JOURNAL

OF THE

AMERICAN SOCIETY OF AGRONOMY

VOLUME 36

1944

PUBLISHED BY THE SOCIETY
GENEVA, N. Y.

IA

CONTENTS

No. 1. JANUARY

No. 2. FEBRUARY

No. 3. MARCH

No. 4. APRIL

No. 5. MAY

No. 6. JUNE

No. 7. JULY

No. 8. AUGUST

No. 9. SEPTEMBER

JOURNAL
OF THE
American Society of Agronomy

VOL. 36 JANUARY, 1944 NO. 1

NUTRIENT BALANCE IN CORN GROWING IN SOUTHERN STATES AS REVEALED BY PURDUE PLANT TISSUE TESTS[1]

MACK DRAKE[2]

CORN yields are generally low in the southern states, even in fertility plots supposedly well fertilized. In order to study the relative causes of these low corn yields a cooperative plan between the Alabama, Georgia, and Mississippi agricultural experiment stations and the National Fertilizer Association was formulated whereby the status of the plant nutrients in the corn plants in these experimental plots could be determined by means of the plant tissue test technic developed at Purdue University.

The Purdue test (1)[3] is used in making determinations for nitrates, phosphorus, and potassium. These tests are semi-quantitative and the relationship of the balances between the nutrients must be considered in interpreting the tests (2).

The nitrate level in the corn plant is determined by splitting the stalk and applying drops of a solution of diphenylamine in sulfuric acid along the exposed tissue. The presence of nitrates is denoted by the blue color developed; the more intense the color, the higher the nitrate supply in the conducting tissue.

Phosphorus tests are made on the finely cut tissue from the new leaf growth before tasseling and later from the base of the tassel. The tissue is shaken in a vial with a dilute solution of KCl and the molybdate-stannous chloride test for phosphorus is made. The phosphorus supply is indicated by the intensity of the blue color developed.

[1]Contribution from the Department of Agronomy, Purdue University, Lafayette, Ind. Received for publication April 10, 1943. Also presented before the meeting of the Association of Southern Agricultural Workers, Memphis, Tenn., February 4, 1942. Published as Purdue University Agricultural Experiment Station Journal Paper No. 95.

[2]Formerly, Graduate Assistant in Agronomy, Purdue University Agricultural Experiment Station; now in the armed forces. On leave of absence February 1 to August 1, 1941, to study at the Alabama Polytechnic Institute, Auburn, Ala., and to make this survey. The writer wishes to express appreciation to the Alabama, Georgia, and Mississippi agricultural experiment stations who cooperated and to the National Fertilizer Association who furnished the funds necessary for this work.

[3]Figures in the parenthesis refer to "Literature Cited", p. 9.

The potassium test is made on the tissue from the base of the leaf if the plants are young and from the leaf nearest the ear if tested after ear emergence. The finely divided tissue is shaken with a solution of sodium cobaltinitrite, and after shaking ethyl alcohol is added. Two minutes after adding the alcohol, the test is read. The amount of potassium present is indicated by the degree of turbidity.

It was hoped that this study would provide some information as to whether or not the yields were limited by an unbalanced nutrient supply. If the supplies of the plant nutrients, nitrogen, phosphorus, and potassium, were found to be sufficient, and balanced, then some other factor would have to be limiting the crop yield.

This study was conducted from May 20 to July 31, 1941. It was planned to make three periodic tests at each experimental location, namely, (a) when five leaves of the corn had emerged, (b) just before tassel emergence, and (c) at the roasting ear stage. Since the soil fertility studies in each state were different, the results for each state are discussed separately.

TESTS ON ALABAMA SOIL FERTILITY PLOTS

The study in Alabama was made in cooperation with Dr. J. W. Tidmore, Mr. J. T. Williamson, and Dr. N. J. Volk of the Alabama Agricultural Experiment Station, Auburn, Ala., on corn plants at eight substations and experimental fields located at Sand Mountain, Wiregrass, Tennessee Valley, Aliceville, Monroeville, Brewton, Alexandria, and Prattville.

Corn plants growing in two series of identical treatments were tested at each of these locations. One series consisted of a 2-year rotation of corn and cotton, with crotalaria seeded in the corn at the last cultivation and with vetch drilled in the cotton in the fall to be turned under for corn in the spring. The crops were fertilized by applying one-third of the minerals to the cotton and the remaining two-thirds to the vetch. Nitrate of soda was used to side-dress two of the plots that had received phosphate and potash, thus supplying nitrogen in addition to that furnished by the vetch. The second series tested included a comparison of fertilizer formulas in a rotation of corn and cotton without the legume crops.

The corn at each of the eight locations was tested at three different stages of growth, with the exception of that at Alexandria which was tested only on two dates.

TWO-YEAR ROTATION EXPERIMENT

This experiment consisted of a 2-year rotation of corn and cotton with summer and winter legumes as an intercrop. Frequently, where the winter legumes had not received any phosphorus, they made very little growth and, therefore, nitrogen fixation was limited. On these plots the corn plants were very deficient in nitrates as shown by the tissue tests. Here nitrogen starvation had limited the growth of the corn to such an extent that the plants tested high in phosphate and potash even though these elements had not been added for the corn.

The plant tissue tests on the corn plants growing where a good yield of fertilized vetch had been plowed under gave high results for nitrates and usually indicated adequate supplies of phosphorus and potassium at the time of ear formation. Some of the highest fertilized vetch plots yielded 80 bushels of corn in 1941 at Aliceville on a Kalmia fine sandy loam, 69 bushels at the Sand Mountain Substation on a Harsells fine sandy loam, and between 50 and 60 bushels at the Alexandria field and the Tennessee Valley Substation on Decatur silt loams. However, the plots at the other locations in Alabama, where vetch was grown and where phosphate and potash had been used, tested high in nitrate, phosphorus, and potassium and yielded only 40 to 50 bushels, thus indicating that some factor other than the supply of these three nutrients was limiting the production.

Fig. 1 gives the results from the Aliceville field where high corn yields were obtained when the tissue tests showed "high" for nitrate, phosphate, and potash. The yield was not stopped at the 80-bushel

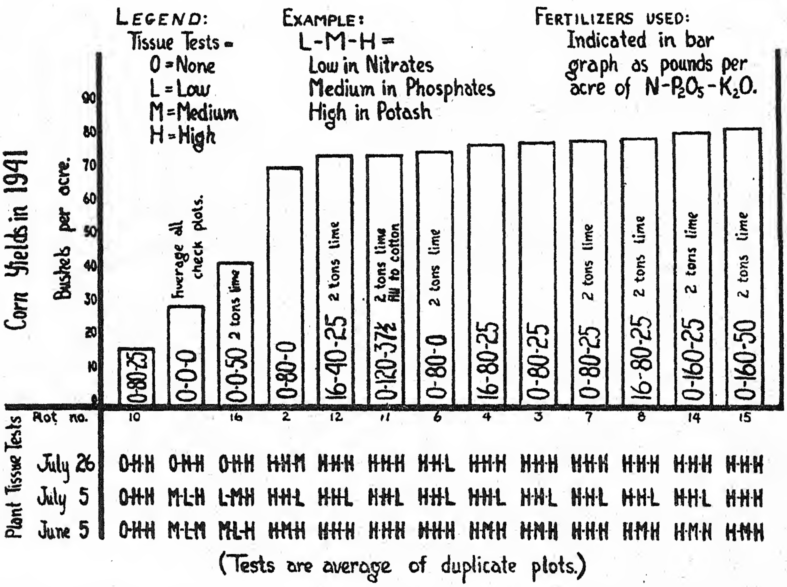


FIG. 1.—Tissue tests of corn grown in a 2-year rotation of corn-crotalaria, cotton-vetch at the Aliceville Experiment Field, Alabama, showing relationships between yields and tests for nitrate, phosphate, and potash in the plants at three periods of growth. Here, up to 80 bushels of corn per acre were produced on some plots when the tests were "high" for the three nutrients, indicating that the yields were not limited by the lack of nitrate, phosphate, or potash but were leveled off because of some other limiting factor. The soil was very dry at the first and last testing periods and moist in the surface on July 5. Tests of untreated soil revealed a pH of 5.4 and "low" phosphate and potash contents by the Purdue method. The amounts of N, P_2O_5, and K_2O indicated on the bar graph are for total pounds of P_2O_5 and K_2O added per acre for the 2 years to the cotton and to the vetch and the nitrogen shown was added to the corn only.

per acre level because of a lack of these three nutrients but was determined by some other limiting yield factor which may have been moisture, even though the rainfall was much better than normal for this area. These yields were the highest since the experiment field was established in 1929.

FERTILIZER FORMULA TEST NO. 1

At the first testing period, the corn plants from the plots of this series at seven of the experimental locations gave low tests for nitrates with the exception of the corn on the plots which had received 18 pounds of nitrogen at planting. Although the practice of applying the nitrogen about 40 days after planting is common, one cannot help asking the question, "How much were these young corn plants injured by starving for nitrates during the early growth period?" In considering such a question one should bear in mind that the corn growing on the plots where vetch had been turned under tested high in nitrates at this same period and thus had not suffered from nitrogen starvation.

At the second testing period, all the plots had been side-dressed with nitrate of soda. At this time, all the corn plants tested high in nitrates except those on the Brewton Experimental Field where there had not been enough rain to move the nitrates into the soil. However, at the time of the third testing, the critical period of ear development, the corn plants of the formula test at the Sand Mountain Substation and the Monroeville Experimental Field (Table 1) were deficient in nitrates. Some of the nitrate tests at Aliceville and Brewton were doubtful as regards an adequate supply, although several of the plots received 36 pounds of nitrogen as nitrate of soda 40 days after planting.

TABLE 1.—*The amounts of nitrate in corn tissue and the amount of nitrogen added to the soil as related to the yields of corn.**

Location	Pounds of nitrogen applied annually per acre 40 days after planting							
	0		12		24		36	
	Nitrate test	Bu. of corn	Nitrate test	Bu. of corn	Nitrate test	Bu. of corn	Nitrate test	Bu. of corn
Alexandria	O/O†	17.4	O/O	25.8	O/H	33.8	H/VH	46.6
Aliceville	O/O	13.6	O/O	22.2	L/M	32.7	M/VH	41.7
Brewton	O/O	10.8	O/O	20.3	O/O	25.9	L/H	30.4
Monroeville	O/O	9.4	L/O	20.7	O/O	30.7	L/L	38.5
Prattville	O/O	8.9	O/O	19.9	L/H	27.5	VH/VH	37.6
Sand Mountain	O/O	7.3	O/O	18.7	O/O	30.6	H/O	40.1
Tenn. Valley	O/O	23.9	O/O	29.8	O/H	35.9	H/VH	41.4

*Data obtained from the 1941 crop of corn grown in formula No. 1 experiment of the Alabama substation and fields. Tissue tests made at approximately roasting ear stage.

†O = No nitrates; L = Low; M = Medium; H = High (adequate), VH = Very high (adequate). Tests for duplicate plots are reported separately, (O/H) indicating no nitrates in the stalk samples from one plot and a high test for nitrates in the stalk from the duplicate plot.

At all the experimental locations in the state, plot No. 7 which had received phosphorus and potash for cotton but only nitrogen for corn, produced corn which tested nearly as high in phosphate and potash and yielded nearly as well in 1941 as the corn on plots that had received phosphorus and potassium directly for the corn. This is a strong indication that some factor other than phosphorus or potassium is limiting the yield of corn. The tissue tests indicated that this factor was nitrogen on the Monroeville, San Mountain, and possibly the Aliceville and Brewton Fields.[4]

The corn of the Alabama experiments used the nitrogen applied very effectively, producing one additional bushel of corn for each 1.5 pounds of nitrogen added (Table 1). Since the yield increases for the second and third increments were nearly as high as for the first and since the plant tissue tests showed 36 pounds of nitrogen to be inadequate at some locations (Table 1), higher rates of nitrogen should prove profitable on some of the Alabama soils, as is indicated in Fig. 2. In this graph it is apparent that more nitrogen would

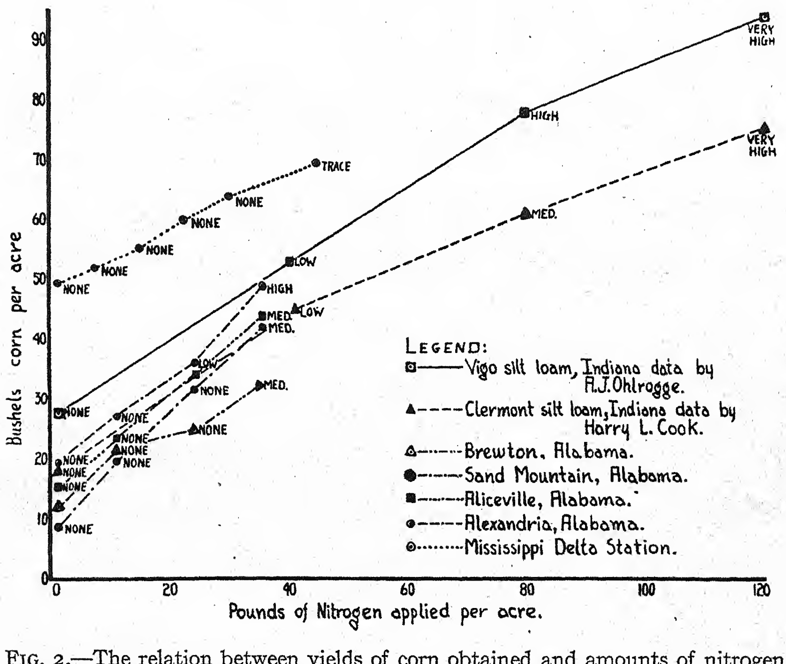


FIG. 2.—The relation between yields of corn obtained and amounts of nitrogen added from experimental plots in Alabama, Mississippi, and Indiana where adequate phosphate and potash had been supplied. The results of tissue tests for nitrates are indicated on the curves. The tests for phosphate and potash gave high results in every instance. The yields from the Mississippi Delta Station were obtained in 1940 and the tissue tests were made in 1941. The Alabama data are from 1941 and the Indiana data from 1939.

[4]This is substantiated by some recent investigations in Indiana (3) where 80 pounds of nitrogen were not adequate to produce maximum corn yields on soils low in organic matter even though adequate phosphate and potash were added.

have increased the corn yields on the more southern plots. It is interesting to note that the slope of the curves in Fig. 2 are similar for the northern and southern regions, suggesting that the efficiency of the corn to use nitrogen in both regions is similar.

TESTS ON GEORGIA CORN FERTILITY PLOTS

The Georgia work was conducted in cooperation with Dr. L. C. Olson, Georgia Experiment Station, Experiment, Ga. The experimental field work was in cooperation with leading farmers.

The Waters and Ursrey farms near Hazelhurst, Ga., on Norfolk sandy loam have been operated at good fertility levels. Soil tests by the Thornton method (1) read high for phosphate and medium and low, respectively, for potash on the Ursrey and Waters farms. Often the plant tissue tests on both farms gave medium to high results for phosphate and potash regardless of whether 0, 24, or 48 pounds of P_2O_5 or K_2O were applied. The tissue tests for nitrates closely paralleled the nitrogen treatments. On studying the 1941 corn yields for the Ursrey and Waters plots, the only consistent yield increase was for the nitrogen fertilization.

Likewise, on the Brooks (Ruston sandy loam) and Baggarley (Norfolk sandy loam) experiment plots, plant tissue tests gave high results for phosphate and potash because of a shortage in nitrogen even where no phosphorus and potassium had been used. Here, too, there was a close correlation between the nitrogen applied and the nitrate tests in the plants. The thin stand of corn on these plots limited the corn yields where the tissue tests gave high results for nitrates, phosphates, and potassium.

The corn on the Akin field plots located on a Kalmia sandy loam gave evidence of severe phosphate starvation symptoms where phosphorus was not applied. All the plants grown on plots without phosphorus were stunted and failed to show the presence of phosphates by the plant tissue tests. The nitrate and phosphate tests paralleled well the fertilizer treatments. Plots which received nitrogen and potash but no phosphate produced 4 to 7 bushels of corn as compared to 25 to 30 bushels where nitrogen, phosphate, and potash were added. Although the tissue tests at tasseling time gave high results for all three nutrients in the corn growing on plots receiving nitrate, phosphate, and potash, the highest corn yields did not exceed 30 bushels per acre, indicating that some other factor was limiting the yields.

Fig. 3 presents the results from the Akin farm where poor corn yields were made with an abundant supply of nitrate, phosphate, and potash present in the plants. Here it is apparent that the yield of corn was low as the result of factors other than the three nutrients tested.

In general, the Georgia plots showed a good relationship between the tissue tests and the crop yields where no nitrogen and 32 pounds of nitrogen had been used. However, there was poor agreement between phosphate and potash applied and the tissue tests, because these nutrients were not the first limiting growth factor. Since phos-

phorus and potassium were not the nutrient elements directly affecting the growth of the plants, the yields did not show any effect from addition of these nutrients. In spite of high tests for nitrate, phosphate, and potash on many plots, the best yields were only 25 to 35 bushels, with the exception of 45 bushels at Hazelhurst, Ga. Some factors other than nitrogen, phosphorus, and potassium must have been limiting growth. Early in the season, moisture was a limiting factor, but at tasseling to roasting ear stage the rainfall appeared to be adequate. Lack of yielding ability of the corn varieties, low rate of planting, and poor stands may have limited to some extent the yields of plots which received complete treatments and which tested high in nutrients at the time of the ear development.

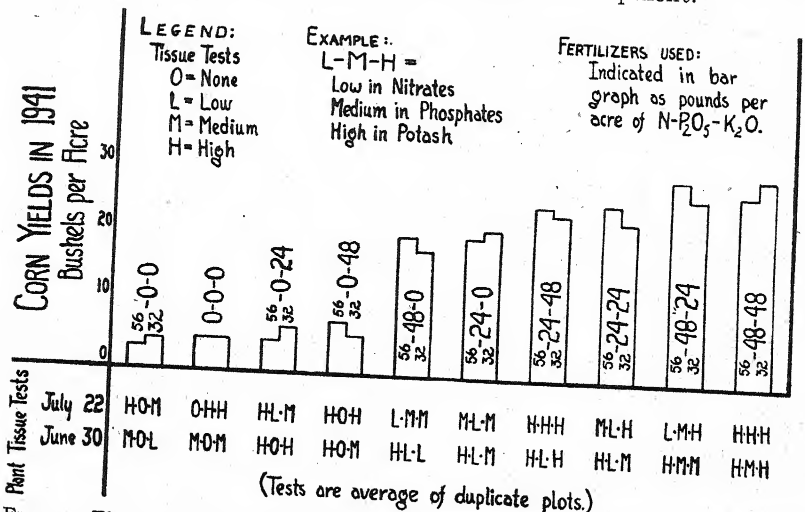


FIG. 3.—The relationship between yields and results of tissue tests for nitrates, phosphate, and potash at two periods of growth in the case of corn grown on the Akin farm, Vaughn, Ga. Here the yield was only 30 bushels of corn per acre on the highest yielding plot. The tissue tests showed "high" on July 22 for nitrate, phosphate, and potash, suggesting that the low yield was caused by some limiting factor other than these three nutrients. The untreated soil tested pH 5.4 and was low in phosphate and potash by the Purdue method. All the fertilizers were used for the corn with the phosphate and potash at planting time and the nitrogen added in side-dress applications.

TESTS ON MISSISSIPPI SOIL FERTILITY PLOTS

These tests were made in cooperation with Dr. W. B. Andrews, Mr. Freeman, Mr. Roy Kuykendall, and Mr. E. B. Ferris of the Mississippi Agricultural Experiment Station and branch experiment stations.

CYANAMID-PHOSPHATE PLACEMENT AND COMBINATION EXPERIMENTS, STATE COLLEGE, MISS.

The corn fertility plots on coastal plain and river terrace soils were all ...

showed that the corn in these experiments was very low in nitrates at tasseling time, although 32 pounds of nitrogen per acre as calcium cyanamid had been applied. The plots receiving 44 pounds of nitrogen per acre produced larger corn stalks of darker green color that tested higher in nitrates than the corn on the plots receiving 32 pounds of nitrogen. However, in half of the locations where 44 pounds of nitrogen were applied, the presence of nitrates was not detected, indicating that this highest rate of nitrogen was inadequate for best yields of corn.

All plots receiving 200 pounds of nitrate of soda as a side-dressing when the corn was knee high produced corn that tested high in nitrates at tasseling; however, these plants were stunted in early growth and were deficient in nitrates on the first testing date before any nitrogen had been added. Field observations showed that 32 pounds of nitrogen as cyanamid added at planting produced large stalks, but the tissue tests showed that the amount of nitrogen was inadequate to carry the corn crop to maturity.

Although phosphorus and nitrogen were the only elements supplied by direct fertilization of the corn, the potash tests on the plants indicated that the potassium supplied by the soil was nearly adequate to balance the 32 pounds of nitrogen applied. Tissue tests on plants running low in nitrates showed an increase or accumulation of potassium from the first to the second and third periods of testing.

RATES OF NITROGEN EXPERIMENTS, STONEVILLE, MISS.

Plant tissue tests were made July 28, 1941, on corn growing on a Sarpy fine sandy loam. At this time the corn was in the late dough stage. Although the leaves on the lower third to lower half of the corn plants on all of these plots were badly fired, there had been sufficient rainfall for a normal crop.

The plant tissue tests showed that even the application of 45 pounds of nitrogen in the row as nitrate of soda was inadequate because none of the plants tested showed the presence of nitrates. From the 1940 yield data, one might conclude that 37½ pounds of nitrogen were sufficient, since 45 pounds produced only one more bushel of corn; however, the plant tests showed that in 1941, 45 pounds of nitrogen were not enough to carry the plant to maturity. Since nitrogen was the factor limiting plant growth, the phosphorus and potassium within the plant could not be used efficiently.

TIME OF NITROGEN APPLICATION EXPERIMENTS, HOLLY SPRINGS, MISS.

Corn was tested on plots on Grenada silt loam which had received nitrogen (a) at planting; (b) when 1, 2, and 3 feet high as side-dressing; and (c) in split applications. The plants receiving split applications tested much higher in nitrates at the critical period of ear formation than the plants receiving all the nitrogen in one application at planting time. Although plants that received 150 pounds of nitrate of soda as a delayed side-dress application tested high in nitrates at ear formation, they were starved for nitrogen during early growth on June 2 when the first tissue tests were made.

Although the split application did not produce more corn in 1941 than the single application, the 1939 and 1940 yields were increased several bushels by placing half of the nitrogen under at planting time and applying the remainder later as a side-dressing.

SUMMARY

A study of the nutrient status in corn plants grown on soil fertility plots of the Alabama, Georgia, and Mississippi agricultural experiment stations was made with the Purdue plant tissue test technic. This was an effort to determine whether a deficiency in nitrogen, phosphate, or potash or a lack of nutrient balances, or some other factors might be the principal causes for the numerous low corn yields in the South.

In general, a lack of nitrogen was found to be the major factor limiting the yields of corn as shown by the plant tissue tests and by harvested results.

Unless winter legumes were well fertilized with phosphorus and potassium, nitrogen was available in such small quantities for the corn that followed the legume that the plants were deficient in nitrates by tasseling time. Corn plants growing on plots where large crops of vetch had been plowed under consistently tested high in nitrates to the roasting ear stage.

The plant tests showed that the practice of growing corn without adding nitrogen until about 40 days after planting generally resulted in nitrogen starvation during the early growth period.

In cases where cotton or some other well-fertilized crop did not precede the corn crop, as on the Georgia river terrace soil, the corn plants tested very low in phosphates. In general, the plant tissue tests indicated that the amounts of phosphorus and potassium were adequate in the plants to balance the limited supply of nitrogen.

In comparing the amount of nitrogen which needs to be added as fertilizer to produce 1 bushel of corn in the southern states with that needed in Indiana, it was found that in both regions approximately 2 pounds (± 0.5) of nitrogen are required to make a bushel of corn.

LITERATURE CITED

1. THORNTON, S. F., CONNOR, S. D., and FRASER, R. R. The use of rapid chemical tests on soils and plants as aids in determining fertilizer needs. Purdue Univ. Agr. Exp. Sta. Circ. 204. (Revised) 1939.
2. SCARSETH, GEORGE D. Soil and plant tissue tests as aids in determining fertilizer needs. Better Crops with Plant Food. March, 1941.
3. ———, COOK, H. L., KRANTZ, B. A., and OHLROGGE, A. J. How to fertilize corn effectively in Indiana. Purdue Univ. Agr. Exp. Sta. Bul. 482. 1943.

SOLUBLE SALT CONTENT OF GREENHOUSE SOILS AS A DIAGNOSTIC AID[1]

F. G. Merkle and E. C. Dunkle[2]

FOR several years the writers have been studying the applicability of soil testing procedures as aids in diagnosing soil problems. In the course of these studies it seemed desirable to obtain samples of soil from farms, gardens, lawns, forests, and greenhouses. In many instances valuable assistance was rendered by the results of analysis. In some cases little or no help was obtained.

Among the soils brought in by extension specialists, county agents, and those sent in by owners, over 300 were greenhouse soils. In the first years of this work almost without fail the person bringing or sending the sample wished to know what nutrient was lacking or what fertilizer should be added. In some instances a deficiency was detected, but in a considerable number of the cases it was evident that there could be no possible deficiency, but that instead, there was strong evidence of excessive concentration of the soil solution. In some cases thousands of dollars were invested in the enterprise and a total loss of crop meant disaster for the season.

Soils were encountered having over 1,000 pounds of nitrate per 2,000,000 pounds of soil, and 600 to 1,500 pounds of potassium according to the methods used (4).[3] Extremely large quantities of the other elements were also found in some instances. Whereas we had been looking for "threshold" values for the various elements, it became apparent that we should also attempt to determine "ceiling" values. This was complicated because of the variation in individual plant tolerances and in such matters as balance among nutrients, adequacy of moisture supply, amount of sunshine, as well as the temperature and relative humidity of the greenhouse atmosphere.

Numerous data are available in the literature dealing with the gross concentration and composition of the soil solution and of aqueous extracts. The concentration has been determined by cryoscopic and conductometric methods and by evaporation of aliquots. It does not seem necessary to discuss such data here.

It is the purpose of this paper to show the relationship between the total solute concentration of soil extracts as shown by evaporation of aliquots and the electrical conductivity of these extracts and to report the order of magnitude of concentrations met with in some of these soils and relationships to plant growth.

EXPERIMENTAL

From our collection of greenhouse soils, 89 samples were selected having medium to high analyses as shown by nutrient tests (4). In this group there were

[1]Contribution from the Department of Agronomy, Pennsylvania State College, State College, Pa. Authorized for publication on May 22, 1943, as paper No. 1180 in the Journal Series of the Pennsylvania Agricultural Experiment Station. Received for publication May 28, 1943.

[2]Professor and Assistant Professor of Soil Technology, respectively.

[3]Figures in parenthesis refer to "Literature Cited", p. 19.

some upon which crops were growing very satisfactorily. There were others from houses where various complaints were made. In some instances the grower would report "plants wilt at noon", or "lower leaves turn yellow and drop off and plant finally dies", or "very small root system", etc.

The aqueous extract was obtained by placing 25 grams of air-dry screened soil and 50 ml distilled water in an Erlenmeyer flask and shaking with a rotary motion occasionally for 30 minutes and then filtering through good quality filter paper. Preliminary trials, using much more thorough shaking, such as shaking for several hours in a shaking machine gave no more, even less, extractable material than this simple rotary shaking. This decrease in concentration with complete dispersion is probably due to increased fixation of certain ions.

The conductivity of the 1:2 extract was determined and an aliquot evaporated to dryness in a tared Pyrex beaker and weighed. After weighing, the residue was treated with 20 ml of 3% H_2O_2 and allowed to digest 4 hours in the covered beaker. The cover was removed and contents allowed to evaporate to dryness and again weighed. This gave the total extractable matter and the extractable organic matter. These were expressed as percentages on the dry soil basis.

The relationship between the total extractable solids obtained by evaporation and the conductivity of the same solution is shown in Figs. 1 and 2. Although the conductivity is controlled by the ionized salts only, and different salts possess different degrees of ionization, and the aqueous extracts contain non-ionizable compounds, even possibly filterable colloids, it is clear from these graphs that the conductivity is so closely related to total extractable solids that it may be used to measure the latter. The good concordance between these two methods is probably due to the fact that soluble and highly ionizable nitrates of calcium and potassium constitute a large portion of the total solids extracted from soils. This concordance between the two methods was observed not only among soils high in soluble salts but also with those very low in soluble matter. No instances in which the two methods disagreed appreciably were observed among all soils examined so far. When the percentage of soluble salts is plotted on the X axis, and conductivity times 10^5 on the Y axis, then $X = 206.3Y - 0.01186$, in case both mineral and organic extractables are present. When the organic extractable material is removed, then $X = 188.1\ Y - 0.032926$. The agreement is so close that there is nothing to be gained by evaporating and weighing the total solids or mineral solids. The conductivity method is simpler and more rapid.

RESULTS

Figs. 1 and 2 and Table 1 include greenhouse soils only from which the soluble material was extracted in a 1:2 extract. Table 2 is presented to show how field soils compare with greenhouse soils. In this case, however, a 1:1 ratio of soil to water was used in extraction. It is apparent that field soils gave 1:1 extracts with conductivities of the order of 23×10^{-5} to 150×10^{-5} mhos, whereas the greenhouse soils gave extracts with conductivities of the order of 50×10^{-5} to $2{,}000 \times 10^{-5}$ mhos. Since the extracts from greenhouse soils were obtained with a higher ratio of water to soil, it is apparent that the soil solution in many of the greenhouse soils is 10 to 100 times as concentrated as is that of field soils.

Further study of Table 2, which involves samples from the Jordan fertility plots, shows a relationship between the treatments and the

TABLE I.—*Soluble matter and electrical conductivity of water extracts from and extractable nutrients in certain greenhouse soils.**

Sample No.	Origin of sample	Remarks	NO_3, lbs.	PO_4, lbs.	K, lbs.	Ca, lbs.	Mg, lbs.	Al, lbs.	pH	LRQ, lbs.	Organic matter, %	Total soluble matter, %	Soluble mineral matter, %	Sp. conductivity $\times 10^5$ mhos
148	Pa. State Col. exp. greenhouse	Plot 8, NPK + N bi-weekly	400	10	100	4,000	300	Trace	7.5	0	—†	—†	—†	104
149	Pa. State Col. exp. greenhouse	Plot 8, M NPK + N bi-weekly	600	40	200	4,000	300	Trace	7.6	0	—	—	—	116
170	Pa. State Col. exp. greenhouse	Plot 19, NPK + N bi-weekly	300	100	50	4,000	300	Trace	7.5	0	—	—	—	82
171	Pa. State Col. exp. greenhouse	Plot 19, M NPK + N bi-weekly	300	70	150	4,000	300	Trace	7.6	0	—	—	—	85
173	Pa. State Col. exp. greenhouse	Plot 20, M PK	50	80	250	4,000	300	Trace	7.4	0	—	—	—	45
711	Pa. State Col. exp. greenhouse	Plot M, 4NPK	300	300	200	5,000	400	Trace	7.3	0	—	—	—	81
712	Pa. State Col. exp. greenhouse	Plot 6, 4NPK	400	40	100	5,000	300	Trace	7.3	0	—	—	—	105
714	Pa. State Col. exp. greenhouse	Plot 7, NP	50	200	50	5,000	300	Trace	7.4	0	—	—	—	56
715	Pa. State Col. exp. greenhouse	Plot 8, M NPK + N bi-weekly	1,200	40	250	5,000	300	Trace	7.2	0	—	—	—	211
16	Pa. State Col. exp. greenhouse	Plot 8, NPK + N bi-weekly	1,000	160	50	5,000	300	Trace	7.2	0	—	—	—	181
36	Pa. State Col. exp. greenhouse	Plot M, NK	100	200	100	5,000	300	Trace	7.6	0	—	—	—	47
37	Pa. State Col. exp. greenhouse	Plot NPK + N bi-weekly	1,000	200	50	5,000	300	Trace	7.5	0	—	—	—	207
38	Pa. State Col. exp. greenhouse	Plot M, NPK + N bi-weekly	1,000	300	100	5,000	300	Trace	7.3	0	—	—	—	224
05	Engstrom, New Castle	Tomatoes do not develop	1,000	120 +	1,750	5,000 +	200 +	0	6.5	1,148	11.4	0.458	0.405	265
32	Weinshenk, New Castle	No complaint	600	100	100	8,000	200 +	1	6.9	—*	8.2	—	—	71
33	Weinshenk, New Castle	No compalint	1,000 +	80	100	10,000 +	200 +	10	6.9	—	9.2	—	—	109
34	Weinshenk, New Castle	No complaint	1,000 +	100	100	10,000 +	200 +	10	7.0	—	7.1	—	—	140
35	Weinshenk, New Castle	No complaint	800	20	300	10,000 +	200 +	10	6.7	—	9.5	—	—	80
36	Weinshenk, New Castle	No complaint	400	60	300	10,000 +	200 +	10	6.8	—	8.4	—	—	65
37	Weinshenk, New Castle	No complaint	1,000	60	140	9,000	200 +	10	6.7	—	10.4	—	—	125
42	Weinshenk, New Castle	Tomatoes and lettuce good	300	40	750	10,000	200	10	7.1	—	8.8	—	—	—*
27	Wm. Bray, Greensburg	Tomatoes fail to grow in spots	2,000 +	160	700 + +	2,000 +	200 +	Trace	7.0	0	7.7	0.796	0.710	436
28	Wm. Bray, Greensburg	of benches	2,000 +	160	700 + +	2,000 +	200 +	Trace	6.9	0	7.2	0.704	0.676	380
8	J. Duff George greenhouses,	Roses } Not planted	1,000 +	60	750	4,000 +	200 +	Trace	6.7	1,150	5.3	0.500	0.437	252
9	Carlisle, Pa.	Roses } What fertilizers	1,000 +	100 +	1,750	4,000 +	200 +	Trace	5.7	3,770	8.3	0.708	0.575	318
0		Carnations } needed?	1,000 +	100	1,750	4,000 +	200 +	Trace	6.8	549	5.6	0.515	0.468	256
15	Pa. State Col. exp. greenhouses	Roses satisfactory	150	120	250	3,000	160	5	4.5	10,707	5.0	0.345	0.275	180
2	Crismann greenhouses,	Chrysanthemums, areas are	500	100	400	4,000	200 +	Trace	6.6	1,118	4.6	0.67	—	493 (1÷1)
3	Punxsutawney, Pa.	stunted and yellow, poor roots	500	50	350	4,000	200 +	Trace	6.5	1,075	5.5	0.58	—	432 (1÷1)
4	John Rothrock, Bangor, Pa.	Cabbage came up in spots	2,000	30	3,000 +	2,000 +	160	Trace	6.7	300	3.7	—	—	635
5		Tomatoes came up in spots	10,000	30	300 +	2,000 +	160	Trace	6.0	700	5.1	—	—	1,993
6	F. W. Knepp, greenhouses	Tomatoes stunted	6,000	200	300	2,000 +	200 +	5	6.8	300	2.9	—	—	1,508
1	McClure, Pa.	Tomatoes slow to grow	200 +	100	350	2,000 +	200 +	0	6.8	0	4.9	0.490	—	340 (1÷1)
5		Tomatoes	400	25	350	4,000 +	80	Trace	7.3	0	4.9	0.841	0.749	380
6	F. W. Knepp greenhouses,	Tomatoes standing still	100	25	Trace	4,000 +	120	Trace	7.5	0	5.5	0.230	0.163	79
9	McClure, Pa.	Tomatoes have not done well	200 +	160 +	350 +	2,000 +	120	Trace	6.7	0	4.8	0.730	0.624	330
0		Tomatoes have not done well	200 +	160 +	350 +	2,000 +	120	Trace	6.5	0	4.2	1.023	0.922	498

*Water extracts were in a 1:2 ratio. Nutrients were extracted with N/4 sodium acetate and are expressed as pounds per 2 million. †Not determined.

TABLE 2.—*Specific conductivities of the 1:1 water extract obtained from soil samples taken from certain plots of the Jordan field experiment and yield of oats for the year 1941.**

Lab. No. of soil sample	Plot No.	Treatment	Conductivity $\times 10^5$ mhos	Oats, bu. per acre
6901	1	O	23	14.6
6903	3	P, 48 lbs. P_2O_5	45	31.1
6904	4	K 100 lbs. K_2O	37	20.6
6914	14	O	32	22.2
6916	16	Manure, 6 tons	71	50.3
6918	18	Manure, 8 tons	69	48.8
6920	20	Manure, 10 tons	72	56.3
6924	24	O	41	19.8
6925	25	PK; 48 lbs. P_2O_5, 100 lbs. K_2O	70	36.8
6926	26	NPK; 24 lbs. N, 48 lbs. P_2O_5, 100 lbs. K_2O	89	43.2
6927	27	NPK; 48 lbs. N, 48 lbs. P_2O_5, 100 lbs. K_2O	90	43.9
6928	28	NPK; 72 lbs. N, 48 lbs. P_2O_5, 100 lbs. K_2O	150	43.6
6930	30	NPK; 24 lbs. N, 48 lbs. P_2O_5, 100 lbs. K_2O	62	32.9
6931	31	NPK; 48 lbs. N, 48 lbs. P_2O_5, 100 lbs. K_2O	77	37.5
6932	32	NPK; 72 lbs. N, 48 lbs. P_2O_5, 100 lbs. K_2O	91	31.9
6936	36	O	51	33.2

*Soil sampled in summer of 1941. Fertilizers and manure applied to corn and wheat in rotation of corn, oats, wheat, clover.

conductivities of the 1:1 extracts. The check plots give the lowest conductivities, varying from 23.3×10^{-5} to 50.6×10^{-5} mhos. This is in the approximate order of the yield of oats obtained from these check plots for the year 1941 when the samples were taken. The effects of the various fertilizer treatments in altering the conductivity of the 1:1 soil extracts of these plots are closely related to the yields of oats in the year 1941. An exception to this agreement is observed in plot 28 which receives 72 pounds of nitrogen on corn and wheat in the rotation. This has a high conductivity due to some sodium residues and this quantity of nitrogen is apparently not needed for oats. Another exception is found in plot 32 which receives 72 pounds of nitrogen on corn and wheat in rotation. This plot has become so acid that yields are depressed in spite of the heavy application of fertilizer. No inference is made that the conductivity of field soils is a single value capable of determining their fertility but, as Hoagland (3) and others have pointed out, those biological and nutritional conditions which are favorable for growth are revealed in a general way in the composition and concentration of the soil solution.

Returning to consideration of the greenhouse soils, there appears to be no advantage in attempting to determine the true concentration of the soil solution as its exists in the soil. The difficulties and inaccuracies in measurement of the solution *in situ* are so great and the difference in concentration which may take place when a soil is allowed to dry from say 20% moisture to 15% moisture is so difficult to evaluate, that it is considered best to measure the conductivity of a 1:1 or 1:2 extract and make all comparisons between soils on that basis.

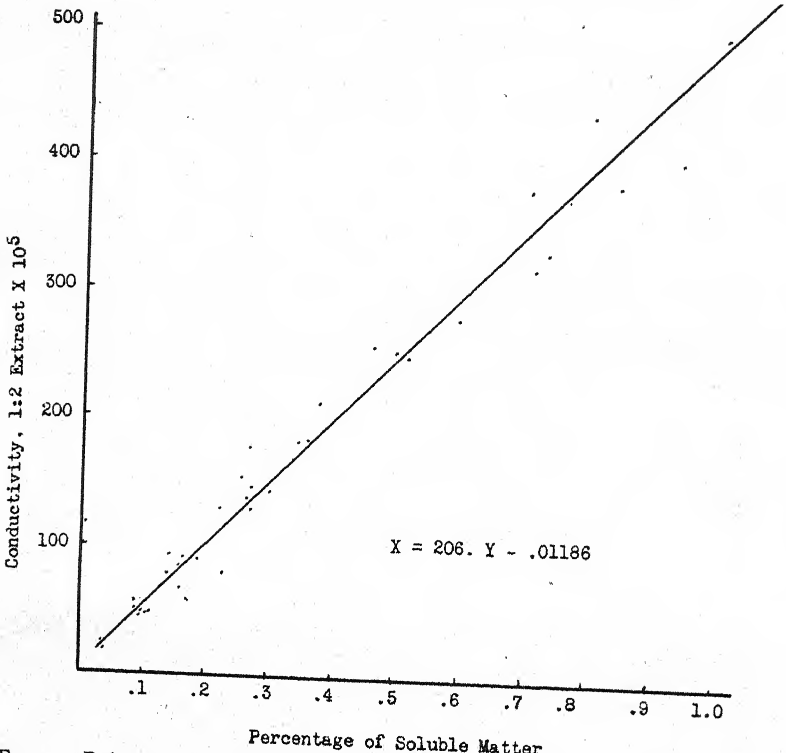


FIG. 1.—Relation between total soluble matter by evaporation in water extract and its conductivity, using a 1:2 soil-water ratio in extraction.

Among the greenhouse soils reported in Table 1, numbers 2736 to 2738, 2711 to 2716, and 2148, 2149, 2170, and 2173 are from the greenhouses of the Pennsylvania State College. In all of these cases tomatoes were growing at the time of sampling and in no case was there apparent injury from overconcentration of salts. The soil medium in all cases was prepared with rotted manure and was well limed. Fertilizer treatments varied from two to three nutrient elements in the fertilizer added, and in the case of numbers 2148, 2149, 2738, 2715, and 2716, nitrate of soda was applied bi-weekly during the growing season. The only plots whose 1:2 extract reached concentrations greater than 200×10^{-5} mhos are those which had received nitrate of soda bi-weekly; the maximum concentration is 224×10^{-5} mhos. The tomato plants on those plots which received bi-weekly applications of nitrate of soda in addition to a good basal soil preparation had crinkly leaves and showed a tendency to wilt occasionally.

Thomas and Mack (7) report that these plots were not benefitted by the bi-weekly treatment as revealed by total yield of fruit. It would seem, therefore, that the "ceiling" conductivity value for tomatoes when the soil is watered frequently is about 200×10^{-5}

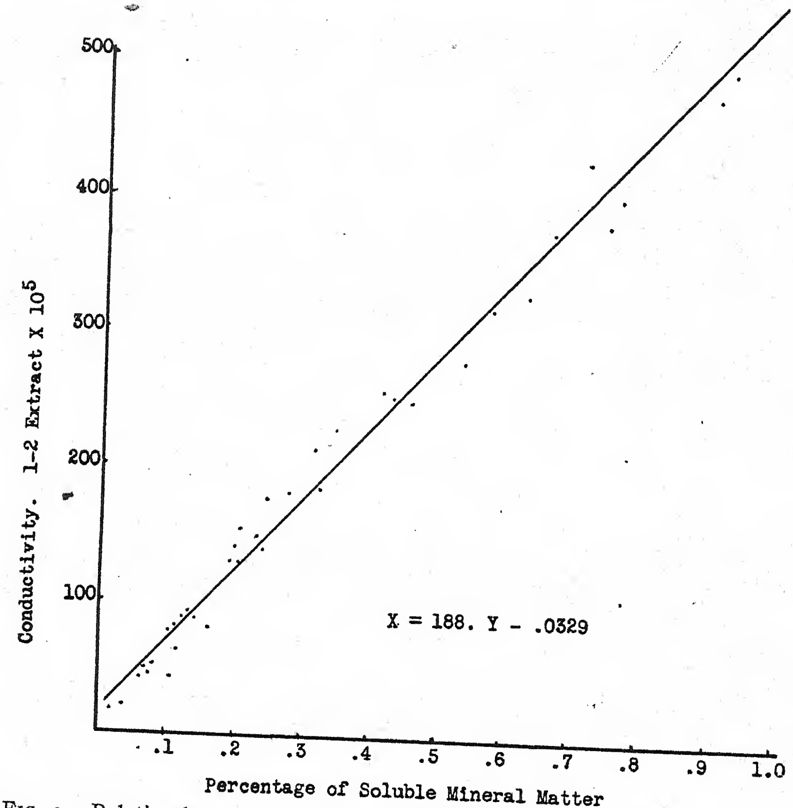


FIG. 2.—Relation between soluble mineral matter in the water extract and its conductivity, using a 1:2 soil-water ratio in extraction.

mhos. It should be pointed out that had the moisture condition been allowed to drop, injury might have occurred on these plots.

Another group of samples which is of assistance in attempting to locate the "ceiling" value for the salt concentrations are Nos. 8405, 8432, 8434, 8435, 8436, 8437, and 8442. These samples, except No. 8405, were all from the greenhouses of a single grower. With the exception of No. 8405, all were reported as producing a good growth of tomatoes. The plants represented by sample 8405 were reported as being tall and slender with a tendency for the fruit to fail to enlarge. This soil had a high content of all nutrients, particularly potassium, and a conductivity of the 1:2 extract of 265×10^{-5} mhos. All the others, though having plenty of nutrients, had concentrations of the 1:2 extract not in excess of 140×10^{-5} mhos. If over concentration is the cause of the difficulty in the case of No. 8405, then it seems that somewhere between 140 and 265 mhos is the "ceiling" value sought.

Samples Nos. 8227 and 8228 are from greenhouses where it was reported that tomato plants grew well on the edges but not in the

middle of the beds. These samples have conductivities of the order of 380×10^{-5} mhos and 436×10^{-5} mhos. Obviously these are cases of over concentration.

Samples Nos. 7498, 7499, and 7500 were taken from composts from greenhouses where roses and carnations were to be planted. The owner wanted to know what fertilizers should be added to the compost. A glance at the analyses and the high conductivities, 252×10^{-5} to 318×10^{-5} mhos, reveals that nothing should be added, but instead a good drenching should be given before planting.

Sample No. 7245 from the rose house of the Pennsylvania State College had a conductivity of 179×10^{-5} and a reasonable supply of all nutrients. Roses were reported as doing well.

Samples Nos. 6872 and 6873 are from chrysanthemum greenhouse beds where plants were reported as being yellow, stunted, and having poor roots. Their 1:1 extracts had conductivities of 493 and 432×10^{-5} mhos. The nutrient analyses show clearly that there could be no possible nutrient deficiency.

Samples Nos. 4264 and 4265 are from greenhouses where cabbage and tomato plants came up only in spots. Their 1:2 extracts had conductivities of 635 and $1,993 \times 10^{-5}$ mhos, values which are unquestionably too high for germination or growth.

One grower over a period of 5 or 6 years has consistently brought in samples which are too high in soluble salts. Sample No. 6811 with a value of 340 mhos, No. 7999 with a value of 330 mhos, No. 8000 with a value of 498 mhos, No. 7455 with a value of 380 mhos, No. 7456 with a value of 79 mhos, and No. 4156 with a value of 1,508 mhos were collected from his greenhouse at different times. He speaks of his plants as being stunted and slow to grow. Plants growing on soil No. 7456 which is obviously not rich enough were described as "standing still."

DISCUSSION

In the light of the above considerations we are tentatively placing the "ceiling" conductivity value of the 1:2 extract at 200×10^{-5} mhos for the more sensitive crops, such as tomatoes, with the proviso that instances may arise when a higher value may not be injurious. Further work to determine the tolerances of different plants is being conducted. The experience of those who have studied the saline soils of the west shows that great differences in tolerance are found among species. Use of this tentative value in addition to the results of a rather complete test for the various nutrients simplifies the process of diagnosis. This value for the 1:2 extract represents very nearly 0.4% soluble matter on the dry soil basis (Fig. 1). This is equivalent to 4,000 p.p.m. of soluble salts. Numerous studies conducted in the saline areas of the arid region show that 4,000 to 5,000 p.p.m. on the dry soil basis marks the danger zone for such crops as wheat and alfalfa.

Correlative evidence as to the validity of the value 200×10^{-5} as the approximate "ceiling" value for the 1:2 extract may be obtained by comparing this value with that of plant root sap. Greathouse (1) has reported root sap and stem sap of some common

plants as having conductivities ranging from 700 to $1{,}500 \times 10^{-5}$ mhos. If we assume that the soil extracts which we obtained are simple dilutions of the existing soil solution, then the soil solution at 20% soil moisture content would be 10 times as great as the 1:2 extract, giving it a value 10 times greater than 200×10^{-5}. This is greater than the conductivity of the root sap. Of course, the root sap is more likely to contain non-electrolytes, such as sugars, which would increase its osmotic pressure without increasing its conductivity.

From the work of White and Ross (8), who determined both the conductivity and freezing point depression on the same displaced soil solutions, it appears that a conductivity of 200×10^{-5} mhos is approximately equivalent to an osmotic pressure of 0.6 atmosphere. If we assume that the concentration of the true soil solution at 20% moisture is 10 times as great as the 1:2 extract, then the osmotic pressure of the soil solution at 20% moisture would be about 6 atmospheres, a value considerably higher than that commonly recommended in culture solutions.

Shive (6) recommends that nutrient culture solutions be made up to an osmotic concentration of 1.75 atmospheres which is much more dilute than our calculated value for the "ceiling" concentration.

McCool and Millar (6) found that the cell sap of roots of peas, grains, and clovers varied from 2 to 12 atmospheres, many being below 6 atmospheres. Hibbard and Harrington (2) showed that the osmotic pressure of root sap of corn varied from 5 to 12 atmospheres, depending on the moisture content of the soil.

From these considerations it is obvious that many of the greenhouse soils examined had salt concentrations entirely too high to be satisfactory culture media for the plants grown, and that any drop in the moisture content of the soil or unusual transpiration demand might react unfavorably upon the plants. Of the 89 samples chosen from our collection of greenhouse soils and reported in Table 3, 36 had conductivity values over 200×10^{-5} mhos and 53 values under 200×10^{-5} mhos. It should be noted that in choosing the samples for this investigation, an attempt was made to include those whose analyses suggested high concentrations. It is obvious that excessive concentration is of common occurrence. About 20% of our collection of greenhouse soils had excessive salt contents.

Among the fertilizers and manure which are likely to produce overconcentration when used in large amounts are the potash salts, particularly Kainit, and manure salts, the inorganic nitrogen fertilizers, urine, manure juice, and poultry manure. The phosphatic fertilizers are not likely to produce overconcentration if the compost used contains considerable clay. Bone products are quite safe.

SUMMARY

The results obtained in testing commercial greenhouse soils for available nutrients revealed that there are many instances in which the growers have used too much soluble fertilizing materials. This study embraced a determination of the water-extractable organic

TABLE 3.—*Specific conductivity and water-soluble matter in the 1:2 extracts of greenhouse soils.*

Sample No.	Total soluble matter, %	Soluble mineral matter, %	Soluble organic matter, %	Conductivity × 10^5 mhos
8405	0.458	0.405	0.053	265
8401	0.148	0.108	0.040	80
8400	0.163	0.134	0.029	90
8396	0.094	0.065	0.029	49
8397	0.095	0.080	0.015	55
8318	0.107	0.081	0.026	50
8261	0.270	0.225	0.044	146
8260	0.090	0.068	0.022	50
8294	0.140	0.134	0.006	92
8227	0.796	0.710	0.086	436
8228	0.704	0.676	0.028	380
8037	0.375	0.213	0.061	213
8042	0.266	0.242	0.024	175
8043	0.219	0.190	0.029	129
7498	0.500	0.437	0.063	252
7499	0.708	0.575	0.133	318
7500	0.515	0.469	0.046	252
7501	0.170	0.135	0.034	69
7502	0.609	0.555	0.054	282
7303	0.940	0.763	0.179	400
7241	0.354	0.318	0.036	183
7245	0.345	0.274	0.071	180
6815	0.159	0.114	0.046	82
6825	0.270	0.200	0.070	130
7955	0.188	0.133	0.055	89
7999	0.730	0.624	0.106	330
8000	1.023	0.922	0.101	498
7625	0.297	0.243	0.054	145
7626	0.253	0.208	0.046	152
7627	0.108	0.060	0.048	49
7842	0.044	0.039	0.004	21
7455	0.841	0.748	0.092	380
7462	0.230	0.163	0.066	79
7112	0.268	0.200	0.068	140
6522	——*	——*	——*	340
6526	——	——	——	332

*Not determined.

and inorganic matter in a large number of greenhouse soils, together with a determination of the electrical conductivity of the aqueous extracts. The following observations and conclusions are made:

1. There is a close relationship between the total soluble matter and the electrical conductivity of aqueous soil extracts.

2. There is a close relationship between the inorganic soluble matter and the electrical conductivity of aqueous soil extracts.

3. The electrical conductivity of the extract is a reliable measure of the soluble matter content.

4. Excessive salt content is of common occurrence among greenhouse soils, about 20% of those encountered being probably excessive.

5. Tentatively the "ceiling value" for germination of several greenhouse plants is placed at 200×10^{-5} mhos for the 1:2 aqueous extract.

6. Measurement of soluble salt content by electrical conductivity is a useful diagnostic aid in the solution of greenhouse soil problems.

LITERATURE CITED

1. GREATHOUSE, G. A. Conductivity measurements of plant sap. Plant Physiol., 13:553. 1938.
2. HIBBARD, R. P., and HARRINGTON, O. E. Depression of the freezing-point in triturated plant tissues and the magnitude of this depression as related to soil moisture. Physiol. Res., 1:441–445. 1916.
3. HOAGLAND, D. R. The freezing point method as an index of variations on the soil solution due to season and crop growth. Jour. Agr. Res., 12:369–395. 1918.
4. MERKLE, F. G. Soil testing: Operation, interpretation, and application. Penn. Agr. Exp. Sta. Bul. 398. 1940.
5. McCOOL, M. M., and MILLAR, C. E. The water content of the soil and the composition and concentration of the soil solution as indicated by the freezing point: Lowerings of the roots and tops of plants. Soil Sci., 3:113. 1917.
6. SHIVE, J. W. The optimum composition and concentration of the salt solution. Dept. Plant Physiol. Rpt., N. J. Agr. Exp. Sta., 361. 1919.
7. THOMAS, W., and MACK, W. B. Foliar diagnosis of differentially fertilized greenhouse tomatoes with and without manure. Jour. Agr. Res., 60:811–833. 1940.
8. WHITE, L. M., and ROSS, W. H. Effect of various grades of fertilizers on the salt content of the soil solution. Jour. Agr. Res., 59:81–100. 1939.

YIELD-DEPRESSION EFFECT OF FERTILIZERS AND ITS MEASUREMENT BY THE UNIVERSAL YIELD DIAGRAM[1]

O. W. WILLCOX[2]

IN PREVIOUS publications (7, 8, 9, 10, 11),[3] the writer has described a universal yield diagram based on the Mitscherlich-Baule theorem and has discussed the use of this diagram for gaining valuable agronomic information not otherwise easily obtainable. The examples of the use of the diagram given in these publications were limited mostly to field experiments where the responses of the crops to increments of plant nutrients were in normal accordance with the original Mitscherlich yield equation $y = A.(1-e^{-cx})$, now more commonly used in the equivalent forms with Briggs logarithms: $y = A.(1-10^{-cx})$ or $\log (A-y) = \log A - cx$.

The present paper deals with cases that do not entirely correspond to the normal equation.

NUTRITIONAL UNBALANCE IN PLANT CULTURE

In experimental field practice with increasing increments of a fertilizer applied to the soil it is often noticed that, while the first few increments give regular and profitable increases of yield, with further increments the yield curve not only ceases to rise but may even turn downward. The action of the fertilizer on the crop may thus present itself in two phases, namely, a phase characterized by increasing yields and a phase characterized by decreasing yields.

The original Mitscherlich yield equation was deduced from experiments wherein conditions were such that only the first phase put in an appearance. So long as these conditions were maintained, the results supported the equation and confirmed the constancy of the effect factor c. Other experimenters, operating under other conditions, encountered the other phase, wherein the equation failed to apply and the constant c took on an appearance of inconstancy. This circumstance was seized upon by Mitscherlich's opponents and taken as a disproof of his law of the constancy of the effect factors of growth factors.

Mitscherlich met this criticism with an extensive new series of experiments (5) in which the three principal plant nutrients, nitrogen, phosphoric acid, and potash, were employed in many different combinations. It was found that so long as the additions of a particular nutrient were kept within certain proportions relative to the other factors of plant growth, no depression of yield appeared. In such cases the equation $y = A\ (1 - 10^{-cx})$ held throughout the whole extent of the yield curve, that is, up to the maximum possible yield, A. If these proportions were not maintained, the yield curve would bend away from the expected normal course and eventually turn

[1]Received for publication June 1, 1943.
[2]Consulting Agrobiologist, 197 Union St., Ridgewood, N. J.
[3]Figures in parenthesis refer to "Literature Cited", p. 30.

downward. The sharpness of the deflection from the normal curve, and the amount by which the yield fell short of A, depended on the degree of unbalance between the nutrients. In general, Mitscherlich found that yield depression was more readily produced with nitrogen than with phosphoric acid, which in turn was more active in this respect than potash.

The yield curves of all the experiments wherein yield depression was produced by unbalanced nutrition thus had two limbs, namely, an initial limb along which the increments of yield exhibited the normal course in accordance with the normal yield equation and a subsequent limb which followed a different law. Mathematical collation of the results showed that both laws could be combined in a single equation that takes account of both the yield-promoting and the yield-depressing actions of the plant nutrient. This general depression equation has the form $y = A\,(1 - 10^{-cx}).10^{-kx^2}$ in which y is the actual yield, A the maximum possible yield under normal conditions, x the amount of nutrient employed, c the constant effect factor of this nutrient, and k a "depression factor" that expresses the difference of the abnormal nutritional set-up from the normal condition. Unlike c, which retains its constancy with all plants under normal conditions, k varies with the circumstances responsible for the condition of unbalance and has to be determined for each case.

Mitscherlich visualized the results of this extensive investigation in a graph which is represented in Fig. 1. This graph exhibits examples of four curves resulting from persistent additions of nitrogen that produced nutritional unbalance to give k the values 0.01, 0.03, 0.06, and 0.15, respectively. These curves are calculated from the equation $y = 100\ (1 - 10^{0.301x}).10^{-kx^2}$ and are well supported by the large volume of experimental data. In this calculation 100 replaces A so that y may be expressed as a percentage of the maximum possible yield; the numeral 0.301 replaces the specific effect factor c of the growth factor when x is expressed in Baule units, as is the case here.

Inspection of Fig. 1 will show that in the absence of unbalance, that is, when $k = 0$, the yield curve rises normally and approaches 100% of A. Where the degree of unbalance is relatively mild, as in the case of the curve for which $k = 0.01$, no sign of depression appears until the increments of the experimental plant nutrient have somewhat exceeded 1 Baule unit. At this point, marked d, where the yield amounts to about 57% of A, the yield curve deflects from the normal curve at a relatively low angle; however, with further increments of the nutrient, the yield continues to increase, but at a rate that is less than is called for by the normal equation. The increases continue at this reduced rate until a point p is reached where the amount of the experimental nutrient has been increased to about 2.5 Baule units and the yield has reached a peak that is only about 72% of A. After that, the curve gradually declines.

It is to be emphasized that these phenomena proceed from the actions of one and the same plant nutrient that is progressively increased relatively to other nutrients. There is here involved what in another place (12) the writer has called the "law" of conflicting attributes of growth factors. In the physiology of plant nutrition.

nitrogen, for example, has on the one hand the positive attribute of a growth-promoter (represented by c), and on the other hand it has the negative attribute of a growth-depresser (represented by k). When the action is positive (as in a balanced environment), c is dominant and k is latent. When the action is negative (as in an unbalanced environment), k comes out of its latency and begins to oppose c. There ensues what might be looked upon as a conflict

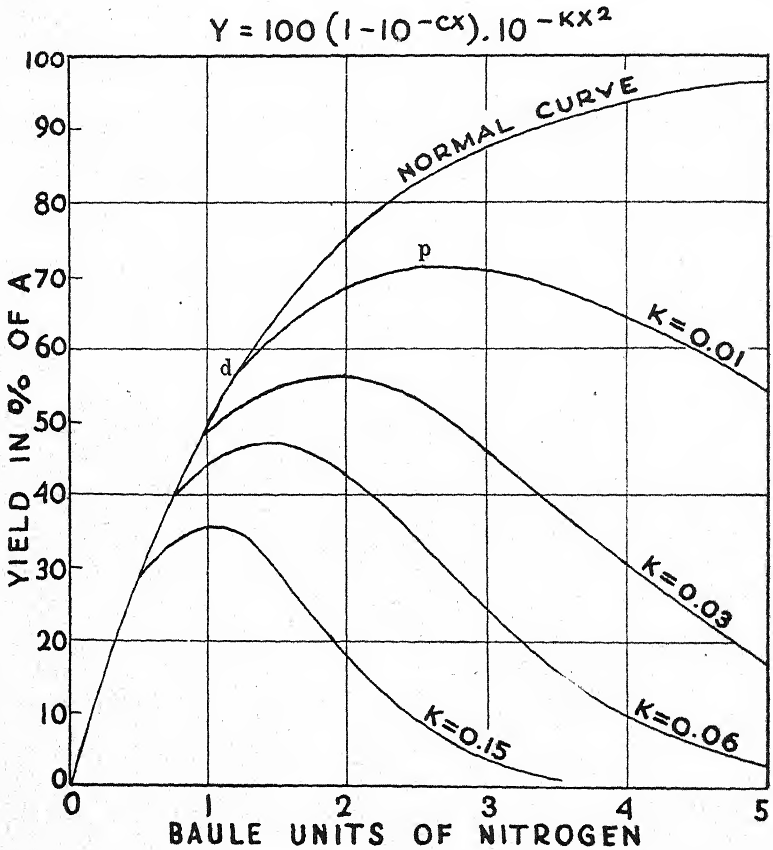


FIG. 1.—Yield-depression curves, showing deflection from normal.

between the two attributes. But c is not overcome all at once; an increase of yield still occurs until k gains leverage to force a decrease. Throughout the whole process c continues to exercise, though ineffectively, *all the force it has* in face of the dominance of k. This persistence of c even under the worst conditions of unbalance is evidenced by the fact that c always retains its full mathematical value in the general depression equation which has been found to represent the whole action. That is to say, c always keeps the value it bears in the normal yield equation. So far from being a

proof of the inconstancy of c these depression phenomena provide a proof that c is really constant.

Out of this extended investigation, which has received much less attention than Mitscherlich's work on the normal yield equation, there has been obtained a clearer perception of what is to be understood by "the balanced nutrition of plants". The nutritional enviornment of plants is balanced when all the factors of plant growth are present and acting in agrobiologically equivalent amounts (13). The agrobiologic equivalent of a factor of plant growth is represented by the value assigned to its effect factor c. The accepted effect factors of the three principal plant nutrients nitrogen, potash, and phosphoric acid are 0.122, 0.33 and 0.60, respectively. When a soil or other medium contains these nutrients in the inverse of these proportions, none of the three has dominance over the others. This concept conflicts with the opinion held by some plant physiologists that nutritional equivalence is related to the molar osmotic pressures of the nutrients.

EXAMPLES FROM FIELD WORK

The research which established the general depression equation was carried out under controlled laboratory conditions with only one variable in a series. The question will present itself as to how the matter stands with fertilizer operations in the open field where any number of variables might appear simultaneously. It is known that various circumstances other than nutritional unbalance may act singly or together to depress the yields of crops. In fields depending on irregular rainfall, drought may raise the concentration of the soil solution and hence intensify the activity of k. It is therefore to be anticipated that variations from Mitscherlich's normal depression equation may be observed in field practice.

The writer has examined the records of numerous published and unpublished field experiments with fertilizers carried out on different crops in different parts of the world and can testify to the frequent occurrence of yield-depressed phenomena, which in many cases show accelerated deviations from the Mitscherlich curves derived from controlled laboratory experiments. So far as the writer has been able to ascertain, nothing has been published on the application of the Mitscherlich depression equation to field work. It may be of interest, therefore, to present a few examples, using data reported by experimenters of known competence.

Fig. 2 is the graph of a nine-object experiment with sodium nitrate on Italian Flint corn reported by Prescott (6) from the Bahtim Experiment Station in Egypt. Prescott recorded his data as kilo grams of sodium nitrate per feddan and his corn yields in pounds per feddan. For applying the universal yield diagram to this experiment it is necessary to recalculate the kilograms of sodium nitrate to equivalent Baule units of nitrogen, and to divide the pounds of corn by 300 to obtain "unit yields" within the scale of the diagram. The data as thus rearranged (average of three experiments in different years showing good concordance) are exhibited in Table 1.

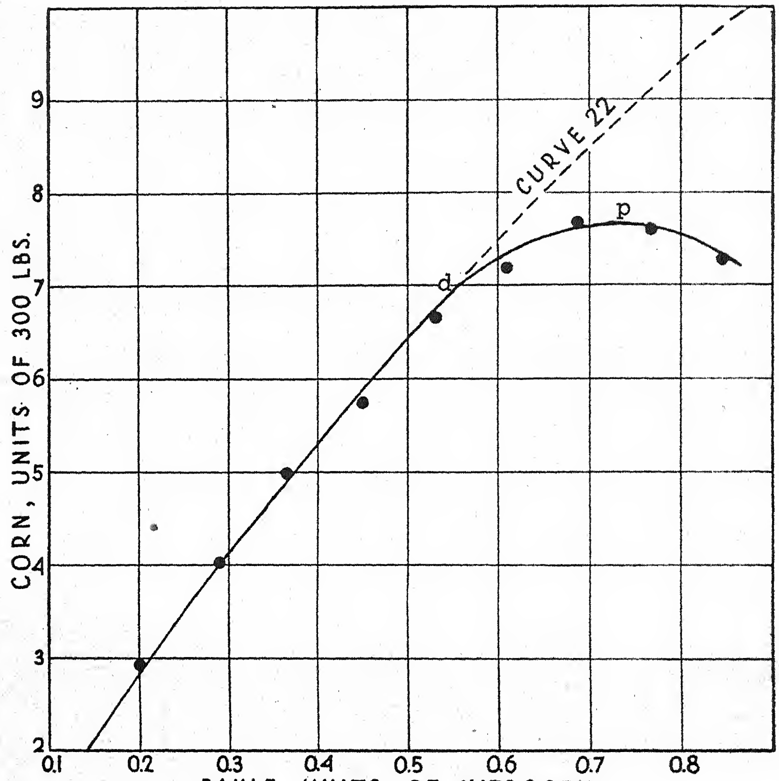


FIG. 2.—Prescott's field test with corn.

When a preliminary plot of these data is made on transparent paper and applied over a copy of the standard universal yield diagram

TABLE 1.—*Prescott's corn experiment.*

$NaNO_3$ per feddan, kilos	Equivalent Baule units of added N	Total Baule units of N in soil*	"Unit yields" of corn	
			Found	Calculated by $y = 22\,(1 - 10^{-cx})$
0	0	0.200	2.92	2.87
50	0.081	0.281	4.02	3.98
100	0.162	0.362	4.96	4.88
150	0.243	0.443	5.73	5.82
200	0.324	0.524	6.63	6.70
250	0.405	0.605	7.17	7.54
300	0.486	0.686	7.69	8.32
350	0.567	0.767	7.60	9.07
400	0.658	0.848	7.30	9.79

*Includes units added plus original soil N. The latter is determined by the intersection of the ordinate which passes through the initial yield point with the axis of abscissas. It is the "*b*" of the well knowm Mitscherlich yield equation $\log (A - y) = \log A - c(x + b)$.

in the described manner (7, 8), it is seen that the results *as a whole* do not correspond to any curve calculated by $y = A\ (1 - 10^{-cx})$. The Mitscherlich yield equation for normal conditions therefore does not apply to this experiment in its entirety. However, the standard yield diagram very clearly shows that the experimental curve is divisible into two distinct limbs. The lower limb, comprising the yields from the first five increments of added nitrogen, fits snugly on curve $A = 22$ of the diagram (Fig. 2). The upper limb, comprising the last four increments, deflects at *d* from the normal curve when the yield has reached about 7 units. Thereafter the actual yield curve continues to rise on a flatter trajectory and reaches a peak at *p*, after which it begins to decline. The whole picture appears to present a typical case of induced yield depression as found in Mitscherlich's pot tests.

It turns out, however, that, while the lower limb of the curve answers very well to the yield equation for normal conditions, the upper limb does not answer to a consistent value for *k*. The depression factor calculated for *k* by $y = 22\ (1 - 10^{-0.301x}).10^{-kx^2}$ for the sixth increment of nitrogen is 0.059, for the seventh 0.075, for the eighth 0.129, and for the ninth 0.179. Obviously, the yield-depressing effect in this soil is the more intense the greater the additions of nitrogen beyond the point of deflection. The readiest explanation seems to be that the soil may have contained a factor or factors that accelerated or catalyzed the depressing action of the excess of nitrogen, or perhaps added its own effect cumulatively on the effect produced by nitrogen alone. The yields therefore fall off more rapidly than would be predicted from the normal depression curve.

Fig. 3 is the graph of a six-object experiment reported by Cooper (3) with ammonium sulfate on tea bushes at the Tocklai Experimental Station at Cinnamara, Assam. In this experiment nitrogen was applied in increments of 0, 20, 40, 60, 80, and 120 pounds per acre and yields are reported as maunds of pucca tea. The data as recalculated for application on the universal yield diagram are given in Table 2.

TABLE 2.—*Cooper's experiment with tea.*

Added N, lbs. per acre	Equivalent Baule units of added N	Total Baule units of N in soil	Unit yields of pucca tea: Actual, Maunds	Unit yields of pucca tea: Actual, Maunds × 5	Unit yields of pucca tea: Required for curve A = 24
0	0	0.674	1.764	8.82	8.82
20	0.0851	0.764	1.928	9.64	9.72
40	0.1702	0.843	2.122	10.61	10.50
60	0.2553	0.930	2.232	11.16	11.38
80	0.3404	1.015	2.344	11.72	12.00
120	0.5106	1.185	2.404	12.02	13.33

The universal yield diagram locates the lower limb of this yield curve, comprising the first four increments, on curve $A = 24$. The rest of the experiment is involved in yield depression. The value of k calculated for the fifth increment is 0.009 and, for the sixth increment 0.031, apparently another case of catalyzed depression.

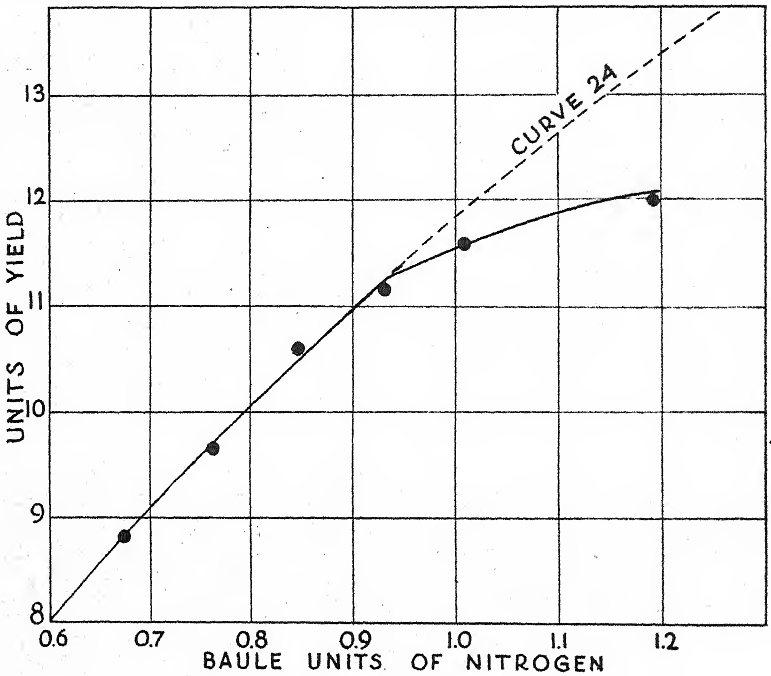


FIG. 3.—Cooper's field test with tea bushes.

Fig. 4 is the graph of a seven-object experiment with ammonium sulfate on sugar cane reported by Clason (2) from the Pasoeroean Sugar Experiment Station in Java. In this experiment the yields of both field cane and crystal sugar are reported. The data as recalculated in the usual manner for diagramming are given in Table 3.

TABLE 3.—*Clason's experiment with sugar cane.*

$(NH_4)_2SO_4$ kg per hectare	Baule units of added N	Total Baule units of N in soil	Actual yields		Required for	
			Cane units	Sugar units	Cane (curve 17)	Sugar (curve 26)
100	0.084	0.521	5.07	8.43	5.20	8.60
200	0.168	0.605	5.81	9.45	5.85	9.52
300	0.252	0.689	6.58	10.55	6.55	10.50
400	0.336	0.773	7.05	11.28	7.05	11.36
500	0.420	0.857	7.48	11.69	7.60	12.18
600	0.504	0.941	7.84	11.69	8.25	13.00
700	0.588	1.025	8.17	11.81	8.61	13.65

The diagram locates the first four cane yields in Clason's experiment on normal curve $A = 17$. Over this traject the cane yields correspond to $y = 17\ (1 - 10^{-0.301x})$. At the fourth increment of nitrogen the cane yield is deflected from the normal at a relatively low angle, indicating a moderate case of nutritional unbalance.

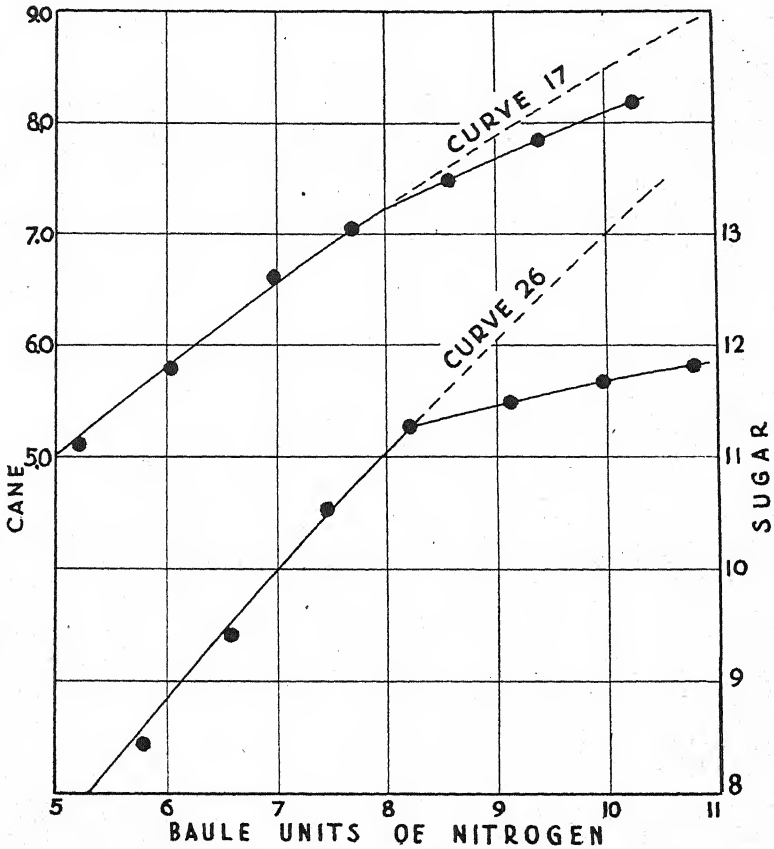


FIG. 4.—Clason's field test with sugar cane.

The values of k on the depression limb are, in succession, 0.013, 0.025, 0.025, and the whole action of nitrogen on cane yields on both limbs corresponds fairly well with $y = 17\ (1 - 10^{-0.301x}).10^{-0.02kx^2}$.

The first four sugar yields in this experiment fall on normal curve $A = 26$. At the fourth increment the deflection of the sugar yield from the normal course is more abrupt than the corresponding limb of the cane curve. Values of k for the last three points of the sugar curve are, in succession, 0.032, 0.051, and 0.06. Evidently, depression of sugar yield has been more catalyzed or accelerated than depression of cane yield. This is probably explainable from the fact that sugar production is a secondary physiologic process, and that as a result

of nutritional unbalance the plants divert more of their energy to the production of tissue at the expense of sugar formation, which was cumulatively reduced in proportion as normal growth of the cane was checked.

Fig. 5 is the graph of an experiment with sodium nitrate on sugar beets reported from Belgium by Decoux (4). In this experiment there were only four treatments, namely, with 0, 75, 150, and 225 kilograms of nitrogen per hectare. These are relatively large quantities, each increment representing 67 pounds of N per acre and thus together they cover a large nutritional range. However, such wide spacing of the increments does not sharply locate the point of deflection when unbalance is present. In the experimental study of this subject it is preferable to have a larger number of points in order to be sure of correctly locating the lower, normal limb.

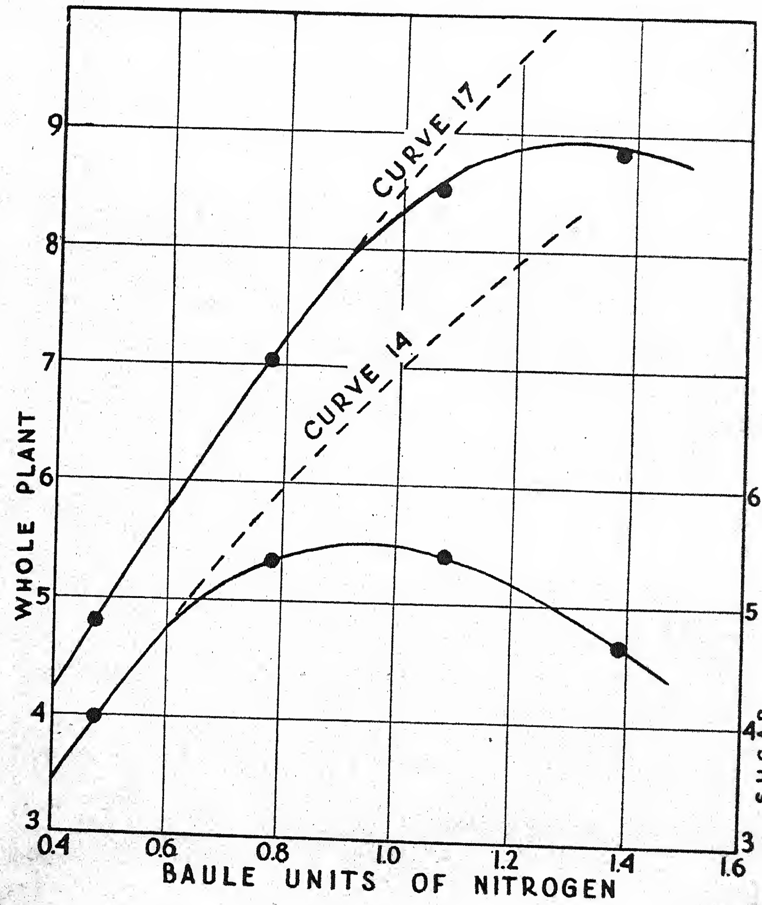


FIG. 5.—Decoux's field test with sugar beets.

The first two increments of Decoux's experiment indicate normal curve $A = 17$ as the curve of yield of the whole plant (roots, crowns, and leaves). The last two increments indicate a depression limb of this curve with *k* values of 0.018 and 0.004, which represent rather mild unbalance so far as yield of the whole plant is concerned. As in Clason's experiment, Decoux's sugar yield is more markedly depressed, the *k* values here being 0.064, 0.11. and 0.14.

DISCUSSION

Before discussing the agronomic implications of these examples of yield depression, occasion will be taken to recall what this writer, among others, has been maintaining, namely, that the "Mitscherlich method" is much more than a pot procedure for "determining the fertilizer requirements of soils", and that many plant physiologists and agronomists, including Mitscherlich himself, have been more or less blind to its larger importance. In its most generalized form, as this writer has stated it in another place (13, page 217), $y = Q.(1 - 10^{-c_1x_1})(1 - 10^{-c_2x_2}) \ldots (1 - 10^{-c_nx_n})$, the Mitscherlich equation is a complete statement of the *normal* quantitative relations between the yields of plants and the concentration or intensity of the factors of plant growth on and beneath a unit area of land surface under normal conditions of plant culture.

In this connection double emphasis is to be laid on the specification for normal conditions of plant culture. The Mitscherlich equation will not hold, and no one should expect it to hold, when a particular system contemplated by this equation is invaded by extraneous forces or disturbed by internal abnormalities. The principles involved in this equation were disclosed and its constants were evaluated by experiments in isolated environments that assured normal, undisturbed interaction between the plants and their growth factors. In fact, the Mitscherlich system derives its great scientific and practical importance precisely from the circumstance that it corresponds only to the optimum and normal conditions of plant life. Being fitted to correspond only to normality, it is a criterion for recognizing and evaluating normality when normality is present, and for detecting and measuring abnormality when that is present.

In the experimental work under consideration in this paper the Mitscherlich equation, in the form $y = A. (1 - 10^{-0.301x})$ given to it by Baule (1) and made easy of application by the universal yield diagram devised by the writer, readily discloses the juxtaposition of a condition of normality with a condition of abnormality. The lower limbs of these yield curves conform about as accurately as any experimenter could expect to the normal law of crop yield under the action of increasing increments of a plant nutrient. The upper limbs of these curves unmistakably indicate the induced appearance of a condition of nutritional unbalance.

The point now is, What information of interest may the practical agronomist deduce from these yield curves?

Turning to Prescott's experiment as diagrammed in Fig. 2, it is deduced that this field, when treated with moderate amounts of

nitrogen, will yield corn at rates corresponding to the normal yield curve $A = 22$. Since the first five increments of yield fall naturally on curve 22, their implication is that if the experimenter should further extend the amount of added nitrogen he could expect a maximum yield of 22 units of corn. Since one unit of corn on the diagram is equal to 300 pounds, the indicated maximum yield is therefore 6,600 pounds, or about 114 bushels of shelled grain. Of course, since the normal yield curve is logarithmic, the response of the crop to successive increments of nitrogen will be smaller and smaller and the process may become uneconomic before the maximum yield of 114 bushels is reached. The point where the increased yield fails to pay for the extra nitrogen will depend on local costs and prices and can readily be figured from market reports and the yield diagram.

The matter of ultimate importance here is recognition of a normal agrobiologic condition which holds promise of attaining corn yields approximating 114 bushels to the acre. However, the upper limb of the curve shows that attainment of the 114-bushel yield is blocked by the intervention of a condition of unbalance which appears to be complicated by factors that catalyze or accelerate the yield-depressive action of otherwise normal increments of nitrogen. The agronomist, therefore, has the choice of confining his future use of nitrogen on this field to an amount that returns less than half the indicated maximum possible yield, or of bestirring himself to find out the reason for the unbalance. If he can find the cause and remove it, he may extend the normal condition to a point where his nitrogen fertilizer will carry the corn crop to a higher and still profitable point on the normal yield curve.

Beyond the prospect of establishing a normal condition such that this field will respond with a nearer approach to 114 bushels when suitably treated with nitrogen, there is a still wider horizon. A crop of 114 bushels to the acre is far beneath the known yielding abilities of superior strains of this species. "Corn Kings" have been crowned in the United States corn belt for producing (with large assistance from unidentified factors) verified yields approaching 200 bushels, and there are scientific grounds for setting the ultimate limit of attainable corn yields well above 200 bushels. If Prescott should succeed in clearing his field from the abnormal condition which prevents him from carrying the yield to 114 bushels by an extended use of nitrogen fertilizer, he would still be only at about the halfway mark. After having thus exhausted the possibilities of the nitrogen factor, the gap between 114 bushels and the "perultimate" maximum of about 225 bushels would direct him to the task of identifying the other factors needing to be raised to higher intensities.

LITERATURE CITED

1. BAULE, B. Mitscherlich's effect law of growth factors. Landwirtschaftliches Jahrbucher, 51:363. 1918.
2. CLASON, E. W. Optimum sulphate of ammonia tests with seven objects. Archief voor de Suikerindustrie in Nederland en Nederlandsch-Indië, 1: 445–448. 1940.

3. COOPER, H. R. Effect on tea crop of different applications of nitrogen as manure in single and divided doses. Indian Tea Assoc. Quart. Jour., Sci. Dept., Part I:1–23. 1931.
4. DECOUX, L., VANDERWAEREN, J., and SIMON, M. Influence of increasing amounts of nitrogen and different kinds of nitrogenous fertilizers on the development of the sugar beet. Pub. de l'Inst. Belge pour l'Amelioration de la Betterave, 7:635–644. 1939.
5. MITSCHERLICH, E. A. The second approximation of the effect law of growth factors. Zeitschrift f. Pflanzenernährung usw. A 12:281. 1928. (See studies on the nutrition of plants and their yields with different fertilizer treatments. Schriften der Königsberger Gelehrten Gesellschaft, Naturwissenschaftliche Klasse, 12: Heft 2. 1935.)
6. PRESCOTT, J. A. Sultanic Society of Agriculture of Egypt, Tech. Sec., Bul. 13. 1924.
7. WILLCOX, O. W. The fertilization of sugar cane. I. A simple graphical method of evaluating tests with fertilizers. Facts About Sugar, 35, No. 12:33–37. 1940.
8. ————. The fertilization of sugar cane. II. The agrobiologic evaluation of some potash tests. Sugar, 36, No. 6:26–29. 1941.
9. ————. The fertilization of sugar cane. III. The agrobiologic evaluation of some nitrogen tests. Sugar, 36, No. 11:26–28, 31. 1941.
10. ————. A critique of field experiments with plant nutrients. Amer. Fert., 95, No. 5:5–7, 26; No. 6:5–11, 24. 1941.
11. ————. Interpretation of Olsen and Shaw's field tests by the Mitscherlich-Baule theorem and the universal yield diagram. Jour. Amer. Soc. Agron., 35:454–459. 1943.
12. ————. Principles of Agrobiology. New York: Palmer Pub. Corp. 1930. (Page 63.)
13. ————. ABC of Agrobiology. New York: W. W. Norton & Co. 1937. (Pages 275–277.)

INFLUENCE OF SIZE OF SEED PIECE UPON THE YIELD OF POTATOES[1]

SHANKAR M. WAKANKAR[2]

IN A previous paper (5)[3] which dealt with the influence of spacing and size of seed piece upon the yield of potatoes, it was shown that the total yield increased with an increase in the size of seed. The results also indicated that small seed pieces yielded a larger percentage and the large seed pieces a smaller percentage of large-sized potato tubers. Bates (2) obtained similar results where small seed pieces produced large individual tubers and large seed pieces reduced the individual size. According to him, yield was greater from large seed pieces because it gave rise to a greater number of "true" plants per hill.

Dealing with the effect of seed size, Salaman (4) has suggested that the amount of food material in the parent tuber is an influencing factor in that the larger the parent tuber, the greater is the initial food supply to the growing plant. In this connection Denny (3) has also shown that the amputation of the parent tubers at different growth stages of the potato plant reduced the total yield if the amputation took place before the plants were 10 inches high, thus emphasizing the importance of stored food materials of the parent tuber on the growth of the potato plant in its earlier stages. It thus became necessary to investigate whether the amount of stored food material of the parent seed tuber or the number of sprouts produced from each tuber, or both, influenced yield.

PROCEDURE AND METHODS

Whole seed tubers of three different sizes, *viz.*, small, medium, and big, being 10, 20, and 40 grams, respectively, of Darjeeling-red potatoes were used. Planting was done on November 11, 1941 (experiment 1) and the hills were lifted on March 4, 1942, when the vines were turning yellow and had not completely dried up. The early lifting of potatoes was necessary because reliable counting of sprouts in the field was only possible at lifting time when the shoots could be removed intact from the ground, examined, and differentiated from the branches.

Experiments 2 and 3 were planted in sand on November 10, 1941. After 24 days, on December 4, when all the sprouts had completely emerged and formed the first leaf, the tubers were taken out and the extra sprouts were removed by a sharp scalpel as described under the experiments. This amputation of sprouts was done in a shaded place and the seed tubers were replanted the same evening in rows in a potato field kept ready for the purpose. Seed tubers with small and weak sprouts were rejected. Almost all the plants wilted, but they picked up and seemed normal within a week's time. The produce of experiments 2 and 3 was gathered on March 15, 1942.

[1]Contribution from the Institute of Agricultural Research, Benares Hindu University, Benares, India. Received for publication June 2, 1943.

[2]On leave for study from the Department of Agriculture, Gwalior, India. The author wishes to express his gratitude to Prof. B. N. Singh for his valuable suggestions during the course of the work and helpful criticism in the preparation of this paper.

[3]Figures in parenthesis refer to "Literature Cited", p. 36.

A uniform spacing of 9 inches between hills was maintained in all the experiments.

All the plants were healthy and the crop condition was good. The yield and the total number of tubers produced in each hill were recorded separately. Average size of the tubers was calculated by dividing the total yield of each hill by the total number of tubers produced. Very small tubers below ½ inch in diameter were rejected and not taken into account.

For the determination of sugars a sample of 50 grams of potato pulp (seed tuber tissue) was weighed into a flask containing 0.25 gram of $CaCl_3$. The material was covered immediately with 75 ml of 95% boiling alcohol and the mixture brought to boiling, after which sufficient hot water was added to bring the extraction medium to 50% alcohol. After removal of alcohol the sugars were estimated in an aqueous solution by the Munson-Walker method. Starch was determined by the official methods (1). Moisture percentage was obtained by drying the samples at 96° C to constant weight and total nitrogen was estimated by the official Gunning method.

RESULTS

EXPERIMENT 1, EFFECT OF SEED SIZE ON NUMBER OF SPROUTS PRODUCED AND YIELD

This experiment was laid out on a small patch in a potato field, and 128 seed potatoes of each size were planted in one-row plots 12 feet long, with eight replications. Shoot counts were taken three times but only the final counts taken during lifting are considered. In the statistical analysis the average of 12 hills was taken as representing one plot. The results are given in Table 1.

TABLE 1.—*Effect of seed size on number of sprouts, yield, and number and size of tubers.**

Seed size, grams	No. of sprouts	Yield in grams	No. of tubers	Av. size of tuber in grams
10	2.01	295	8.65	34.2
20	2.99	324	11.25	29.0
40	3.85	354	13.73	25.8
S.E.	±0.34	±9.24	±0.64	±1.80

*Average for each hill.

The data point to the fact that big seed produces a larger number of tubers, a greater total yield, and more sprouts per seed tuber than medium seed. Medium seed in its turn also produces a greater number of sprouts, more yield, and a larger number of tubers to the hill when compared to the small seed. The average size of individual tubers from big seed is reduced, whereas it is increased from small seed, tubers from medium seed occupying an intermediate position.

EXPERIMENT 2, EFFECT OF NUMBER OF SPROUTS ON YIELD

For this experiment whole seed tubers of the big size, *viz.*, 40 grams in weight, were used. They were first germinated in sand and after

24 days were divided into three lots of 96 seed tubers each. In the first lot one sprout, in the second lot two sprouts, and in the third three sprouts were kept and any remaining sprouts removed, care being taken that an equal amount of injury was inflicted on each seed tuber. These seed tubers were then planted in one-row plots 12 feet long, with six replications. The data of experiments 2 and 3 were calculated together and hence a common standard error has been given. The results are presented in Table 2.

TABLE 2.—*Effect of number of sprouts on yield, number, and size of tubers produced.**

Seed size and No. of sprouts	Yield in in grams	No. of tubers	Av. size of tubers in grams
40 grams with 1 sprout........	260	6.64	39.3
40 grams with 2 sprouts........	301	8.55	35.3
40 grams with 3 sprouts........	337	12.18	27.6
S.E......................	±11.34	±0.31	±2.30

*Average for each hill.

The results show that keeping the seed size constant, the yield, total number of tubers produced, and their individual size are affected considerably by the number of sprouts per hill. With one sprout to each hill, the total number of tubers formed and the yield of each hill is less, but the individual size of the tubers produced is increased. On the other hand, when three sprouts are kept to each hill, the total yield and the number of tubers formed is increased, but their relative size is reduced.

EXPERIMENT 3, EFFECT OF SIZE OF SEED ON YIELD WITH ONE SPROUT TO EACH SEED PIECE

In this experiment seed tubers of three sizes, *viz.*, 10, 20, and 40 grams, were used and were germinated in sand. Only one sprout was allowed on each seed tuber in this test and the extra sprouts were removed. They were then planted as usual in 12-foot one-row plots, with six replications. The results are given in Table 3.

TABLE 3.—*Effect of seed size on yield, number, and size of tubers produced, keeping one sprout to each seed piece.**

Seed size, grams	Yield in grams	No. of tubers	Av. size of tubers in grams
10......................	259	6.56	39.5
20......................	265	6.80	39.0
40......................	260	6.64	39.3
S.E......................	±11.34	±0.31	±2.30

*Average for each hill.

From the results presented in Table 3 it is evident that seed size has no significant effect on the total yield, total number of tubers, and individual size of the tubers produced.

The data of the present experiments have shown that the yield, total number of tubers produced by each seed tuber, and their individual size is governed by the number of sprouts produced rather than by the amount of food material stored in them. Within the range of 10 to 40 grams, the amount of stored food material has no influence upon yield and grade of produce. Big seed tubers obviously possess a greater store of food material as compared to small ones, but it must be remembered that they produce more sprouts and it is due to their capacity of producing a greater number of sprouts that a higher yield is obtained from large seed pieces.

CHEMICAL COMPOSITION OF SEED TUBER TISSUE

Seed tuber tissue for various chemical determinations was obtained from experiments 2 and 3. The tissue was analyzed at the following stages: Stage 1, when the sprouts had emerged and formed the first leaf. This stage was obtained 24 days after planting and coincided with the time of replanting. Stage 2, when the plants were about 8 inches high and were just forming tubers on stolons. This stage was obtained 40 days after planting. Stage 3, when the plants were about 16 inches in height. At this stage tubers of about ¾ inch in diameter were being formed. This stage was 60 days after planting. No attempt was made to analyze the seed tuber tissue at later stages as the majority of seed tubers were found to be rotted. The analysis of seed tuber tissue is given in Table 4.

TABLE 4.—*Chemical composition of seed tuber tissue at three stages of growth of the potato plant.*

Seed size and No. of sprouts	Stage of develop-ment of plant	Percentage composition on fresh weight basis*				
		Mois-ture	Dry matter	Starch	Total sugars	Total N
Small with 1 sprout..	1	86.5	13.5	6.8	2.18	0.36
	2	93.7	6.3	2.4	3.01	0.14
	3	97.8	2.2	0.5	1.30	0.08
Large with 1 sprout..	1	84.0	16.0	9.4	1.84	0.45
	2	91.1	8.9	4.9	2.46	0.29
	3	95.4	4.6	1.4	1.58	0.14
Large with 3 sprouts	1	84.4	15.6	9.0	1.76	0.42
	2	92.3	7.7	4.0	2.02	0.20
	3	96.2	3.8	1.2	1.40	0.09

*Average for three determinations.

As judged by the chemical studies (Table 4), the general changes noted are rapid loss of dry matter, increase in moisture content, increase in total sugars at stage 2 and a fall at stage 3, and a decrease in starch and total nitrogen. The effect of seed size on the chemical composition of the seed tuber tissue at three stages of growth of the potato plant is that the loss of dry matter, starch, and nitrogen is greater from small seed than from the larger and that moisture

and total sugar content increased to a greater extent in the small as compared to the larger seed. These observations suggest that a comparatively greater percentage of stored food material is used from small seed than from the larger seed. But as this greater depletion of food materials from small seed does not affect the yield adversely (experiment 3), it can be assumed that the small amount of food material present in it is not a factor affecting the growth of the potato plant.

The effect of number of sprouts on seed tuber composition is not very significant, but there are indications that a greater percentage of food material is removed from those seed tubers which have the greater number of sprouts.

SUMMARY

Experiments were conducted to study the relationship of seed piece size to yield in potatoes and the following results obtained:

1. Large seed pieces produce a greater number of sprouts, a greater yield, and a larger number of tubers per hill as compared to the small seed. The size of the individual tubers is reduced in case of large seed pieces, whereas it is increased with small seed pieces.

2. Keeping the size of the seed tuber constant, it has been found that yield and other characteristics of tubers produced are influenced by the number of sprouts per hill.

3. Size of seed piece within the range of 10 to 40 grams, with one sprout to each seed piece, has no effect on yield and other tuber characters.

4. Large seed pieces give higher yields because of their capacity to produce more sprouts per hill.

5. Determinations of the chemical composition of seed tuber tissue at three stages of growth of the potato plant show that there is a comparatively more rapid depletion of stored food material from the small seed piece than from the larger ones. As this depletion does not affect yield, it is presumed that the amount of stored food material in the seed tuber, or seed piece size, has no relation to yield. These results also indicate that with an increased number of sprouts to each seed piece, there is more demand on the stored food material of the seed tuber.

LITERATURE CITED

1. Association of Official Agricultural Chemists. Official and Tentative Methods of Analysis. Washington, D. C. 1930.
2. Bates, G. H. A study of factors influencing the size of potato tubers. Jour. Agr. Sci., 25:297–313. 1935.
3. Denny, F. E. Role of mother-tuber in growth of potato plant. Bot. Gaz., 87:157–194. 1929.
4. Salaman, R. N. The determination of the best method for estimating potato yields together with a further note on the influence of size of seed on the character and yield of potato. Jour. Agr. Sci., 13:361–389. 1923.
5. Singh, B. N., and Wakankar, S. M. Effect of spacing and seed size on yield of potatoes. Jour. Amer. Soc. Agron., 35:613–616. 1943.

THE SEASONAL OCCURRENCE OF SOIL EROSION IN NEW YORK AS RELATED TO RAINFALL INTENSITIES[1]

J. LAMB, JR., G. R. FREE, AND H. H. WILSON, JR.[2]

IF IT were possible to predict with any reasonable degree of accuracy the time of year when soil erosion is likely to occur, it would simplify the problems of control. Cropping practices and other necessary measures could be adjusted to provide the soil with adequate protection during critical periods.

Neal (5)[3] and others have shown that rainfall intensity is probably the most important of the factors that influence runoff and soil erosion. Later studies by Borst and Woodburn (3) and Laws (4) indicate that the greater impact of the larger drops, which seem to occur with the more intense rainfall of continental areas, may be as important or even more important than the intensity factor alone. Studies of the effects of intensity of natural rainfall in such areas are combined with those of impact.

Blumenstock (2) finds the highest intensity rainstorms occurring in the summer months in Washington, D. C., Elkins, W. Va., and Lynchburg, Va. The same condition is indicated for New York, in a general way, by Yarnell (7).

The purpose of this report is to present specific data for New York conditions with recommendations for erosion control practices.

METHODS

Rainfall, runoff, and soil loss measurements were made in three locations in the State, namely, 17 miles southwest of Ithaca at the Arnot Forest; 45 miles northwest of Ithaca at Geneva; and 45 miles northeast of Ithaca near Marcellus. The erosion station at the Arnot Forest is typical of the Appalachian Plateau of southern New York and northern Pennsylvania. The experimental plots are at an elevation of 1,900 feet on Bath flaggy silt loam, with a 20% slope to the southeast. The plots at the New York State Agricultural Experiment Station, Geneva, have an elevation of 600 feet. They are located on two soil series, Dunkirk silty clay loam, 5% slope to the south; and Ontario silt loam, 8% slope to the north. Both are representative of the Erie-Mohawk-Ontario plain. The Marcellus erosion station is located on Honeoye silt loam at 1,000 feet elevation and represents the deep limestone till soils of the state. The plots have an 18% slope, southwest exposure.

The precipitation was measured through the full year with recording type rain and snow gages and standard U. S. Weather Bureau pattern gages. More than

---

[1]Contribution from the Division of Research, Soil Conservation Service, U. S. Dept. of Agriculture, in cooperation with the Cornell University Agricultural Experiment Station, Ithaca, N. Y. Received for publication June 4, 1943.

[2]Project Supervisor, Associate Soil Conservationist, and Junior Soil Conservationist, respectively. We wish to express our appreciation to Dr. A. F. Gustafson, Professor of Soil Technology, Cornell University Agricultural Experiment Station, for suggestions, and to Mr. E. A. Carleton, Assistant Soil Technologist, for suggestions and data from the erosion experiments carried out under his direction at Geneva, N. Y.

[3]Figures in parenthesis refer to "Literature Cited", p. 45.

one gage of each type was in use at each station and records were secured for all storms. Rainfall intensity was defined in terms of the maximum rate of fall for 15 minutes expressed in terms of inches per hour, a proposed method of reflecting the erosive character of the rain.

The entire soil and water runoff from each location was caught from plots 72.6 by 6 feet at the Arnot and Geneva stations. A part of the runoff was caught through fractional divisors from plots 72.6 by 21 feet at Marcellus. The sides and upper ends of these plots were formed by steel borders projecting approximately 4 inches above the soil surface and extending into the soil from 8 to 14 inches. A covered gutter and flume at the bottom of the slope led the runoff into the tanks. Single plots were used at Geneva throughout the period and at the Arnot station from 1935–37. Duplicate plots were used at Marcellus, and beginning with 1938 at the Arnot station.

Since the purpose of the experiments was to study rainfall characteristics that affect soil erosion, the factor of cover was eliminated by keeping the soil fallow, cultivating at the same time as nearby corn plots, and pulling weeds as they appeared. Vegetation may easily mask the effect of many other factors that are associated with erosion. At the Arnot station a rain of June 18, 1936, caused a loss of 17,141 pounds of soil per acre within 10 minutes from fallow land, but no soil loss occurred from an adjoining plot protected by a heavy growth of clover and grass mixture. It is true that certain physical and chemical changes take place in a soil that is held fallow for a period of years that might materially increase its erodibility. However, at the Arnot station plot A8, held fallow, gradually decreased in erodibility as cultivation brought more stones to the surface and fine soil was washed from about the stones. Plot A7, held fallow with stones above 2 inches in largest dimension removed, lost from two to six times as much soil as plot A8. Because surface stones slow down the erosion process, beginning with 1938 the losses from plots A7 and A8 have been averaged for each rain.

RAINFALL INTENSITY AND EROSION

During the period May 1935 through December 1942 at the Arnot station, 157 rains caused measurable soil loss. A study of the data indicates that there is a relation between the total amount of rainfall and the loss of soil by washing, but not a consistent relation. A rain of 1.5 inches caused the greatest soil loss, 17,141 pounds of soil per acre; but it fell at a maximum intensity of 4.6 inches per hour per 15 minutes. Another rain of 2.7 inches fell at a maximum rate of 0.4 inch per hour per 15 minutes and resulted in a soil loss of only 119 pounds per acre.

It is the high intensity rains that cause severe erosion in this region, as illustrated in Fig. 1. When the soil loss was above 100 pounds per acre, it was found to increase much more rapidly than the intensity in a ratio approximating the square of the maximum 15-minute intensity. Maximum intensities were determined for 5-minute and for 30-minute periods, and these intensity data were also found to correlate with the soil loss data. In general, however, the maximum intensity for 15 minutes appeared to be the best measure of the erosive character of the storm, even though the 15-minute interval introduced a volume factor of greater size than the 5-minute interval. The amount of moisture already in the soil at the time the rain

occurred was also an important factor in regard to runoff and soil loss. The relative runoff for dry, moist, and wet conditions was 0.17, 0.21, and 0.23 inch, respectively. The average soil loss under similar conditions was 687, 1,086, and 1,627 pounds of soil per acre, a greater percentage increase than in the case of runoff. Observations indicate that fields which slope to the south or southwest with more direct exposure to the sun heat have less snow cover, a longer period of alternate freezing and thawing in the late winter, and thus more winter erosion.

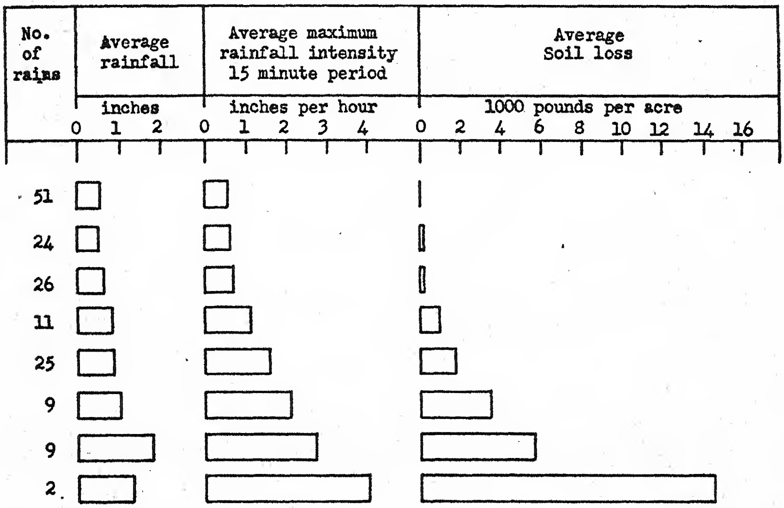


FIG. 1.—The relation of amount and intensity of rainfall to the extent of soil loss on Bath soil, clean cultivated, no crop, 20% slope, plots 72.6 feet by 6 feet, is indicated above. The rains are grouped in order of soil losses. The greatest soil loss occurred when a large amount of rain fell in a short time. For the period covered ending December 1942, 7 years and 8 months, the 20 highest intensity rains, 13% of the total number of rains producing runoff, caused 57% of the total soil loss.

From Fig. 2 it is shown that the high intensity rains occurred during the period of June 1 to September 19, approximately 100 days, and the greatest soil loss occurred with those rains.

It will be noted that the peak of greatest average soil loss occurs during the last 10 days of July, whereas the peaks of maximum intensities occur during June and September. The latter peaks are based upon single storms only. Total soil losses are, of course, dependent upon the number of storms, their duration, and their time of occurrence with respect to antecedent rainfall and soil condition as well as upon intensity. With few exceptions the October rains have been low in intensity. The major part of the precipitation of November through April is snow. No late winter soil loss has occurred at the Arnot. Plots A7 and A8 have a southeast exposure, are protected from the prevailing west winds, and, during the greater part of the winter, are covered with snow and are not frozen. The

snow protects the soil from the impact of rain drops and acts as a sponge in absorbing water. Since soils that are frozen or partially frozen absorb little water (1), the rainfall intensity-soil loss relationship does not hold for such conditions.

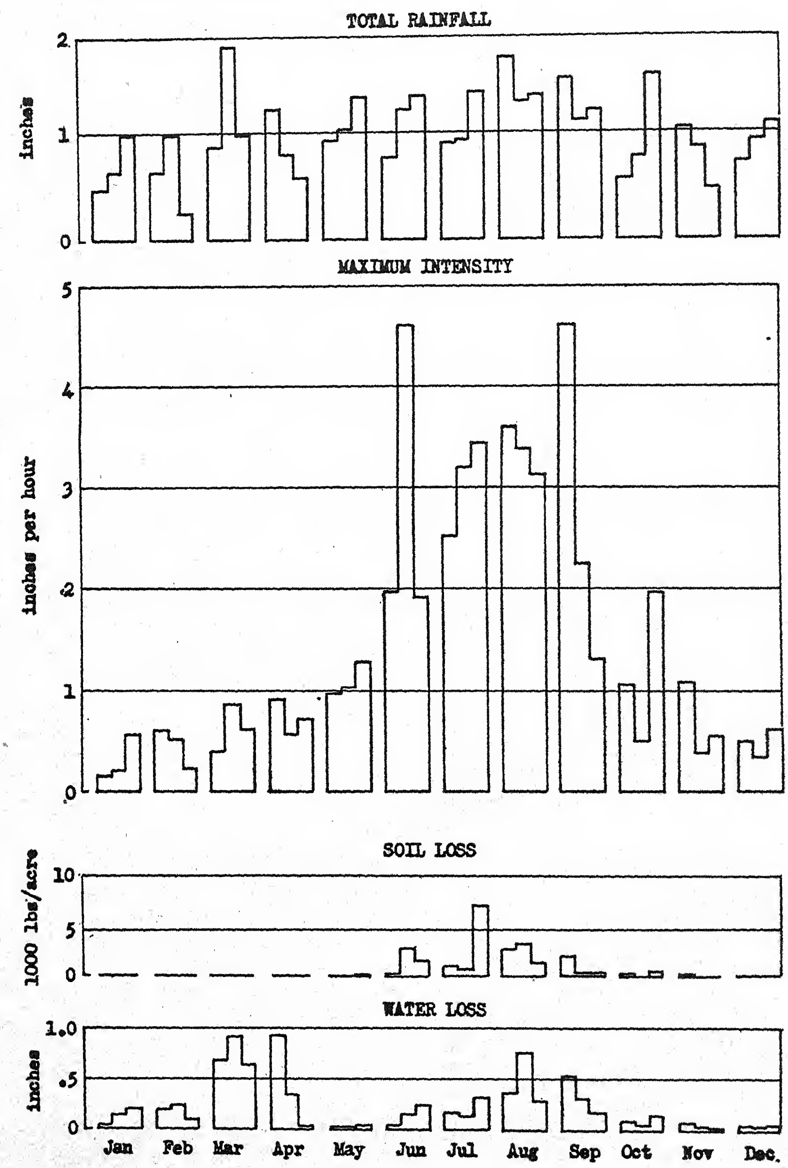


FIG. 2.—Total average rainfall by 10-day periods, highest 15-minute intensity during those periods, and average soil and water lost in runoff from fallow plots of Bath flaggy silt loam, 20% slope, Arnot station, 1935 through 1942.

At Geneva high intensity rains of the thunderstorm type (Fig. 3) have caused the major soil losses. Winter erosion may be severe at the 600 feet elevation of these plots, especially in the case of the Dunkirk soil with a 5% slope to the south. This loss amounted to 10.9 tons per acre the winter of 1941–42 and has averaged 5.2 tons since 1936. The Ontario soil plots with an 8% slope to the north had an average winter loss of 1.7 tons per acre and the largest loss was 4.7 tons in the winter of 1937–38.

The rainfall intensity has been lower than that at the Arnot station, but these soils are less stony and less absorptive than the Bath flaggy silt loam and more erodible. The Ontario fallow land has lost top soil at the rate of approximately an inch in 8 years, and the Dunkirk more than an inch in 7 years. Determination of infiltration capacities and erodibility of several soils in New York, Ohio, Georgia, and North Carolina, indicates that the Dunkirk is one of the most erodible in the study (6). The Ontario soil lost 23.9 tons of soil per acre with one rain by sheet erosion without the formation of rills, but when the Dunkirk soil lost 45.8 tons of soil with one rain, rills were formed; however, the first cultivation destroyed the surface evidence of this serious erosion.

At Marcellus the period when most of the erosion has occurred corresponds with the period of high intensity summer rainfall (Fig. 4). Water losses have been highest during the early spring when the snow is melting. The exposed soil is frequently saturated and relatively low intensity rains have caused heavy soil loss. Where a shallow layer of surface soil is not frozen and rests on a frozen layer, a mixture of soil and water forms which flows readily on the 18% slope plots, unless bound by surface litter or root growth. The soil loss in 1941 was 155.1 tons per acre, more than an inch of top soil in 1 year, and was due to the large number of relatively high intensity rains. Approximately 30 tons per acre were lost during each of two storms. Ninety-three per cent of the total soil loss from fallow ground has been caused by storms exceeding a maximum intensity of 0.80 inch per hour for 15 minutes. There were 3 such storms in 1939, 3 in 1940, 19 in 1941, and 5 in 1942. The one storm in March, 1942, the highest intensity recorded at any of the stations in the early spring resulted in a loss of 20 tons of soil per acre from the fallow plot, and caused severe erosion damage throughout central New York. Rainfall intensity at Marcellus has been lower than that at the Arnot but, as at Geneva, the soil loss has been more.

EXCESSIVE RAIN STORMS

The 8 years during which rainfall records were taken at the Arnot station, the 7 at Geneva, and the 4 at Marcellus are far too short a period to establish a general trend; yet the same seasonal occurrence of high intensity rainstorms is shown by long-time Weather Bureau records for New York. From 1903 through 1937 there were 530 excessive rains at nine stations in the state and only five of these were outside the May-October period, and 87% occurred June through September. The U. S. Weather Bureau does not measure intensity

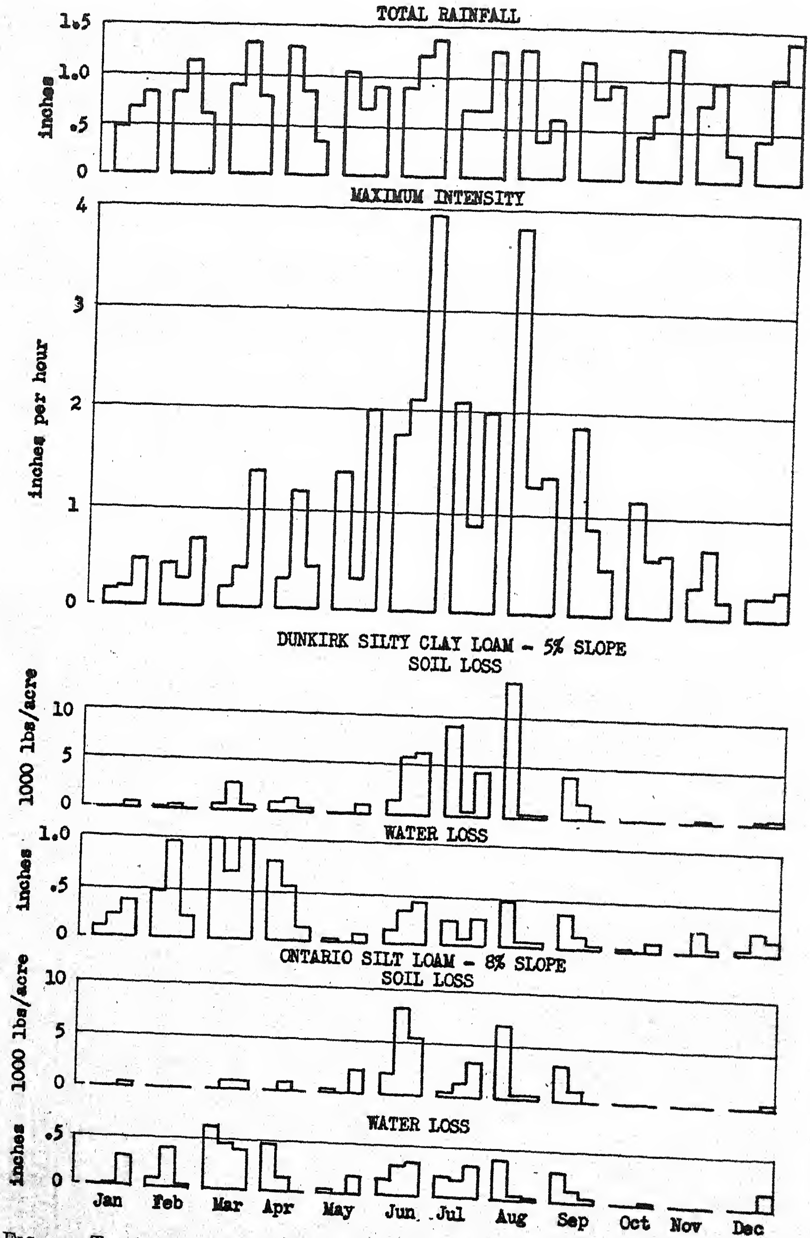


FIG. 3.—Total average rainfall by 10-day periods, highest 15-minute intensity during those periods, and average soil and water lost in runoff from fallow plots on two soils at Geneva, 1936 through 1942.

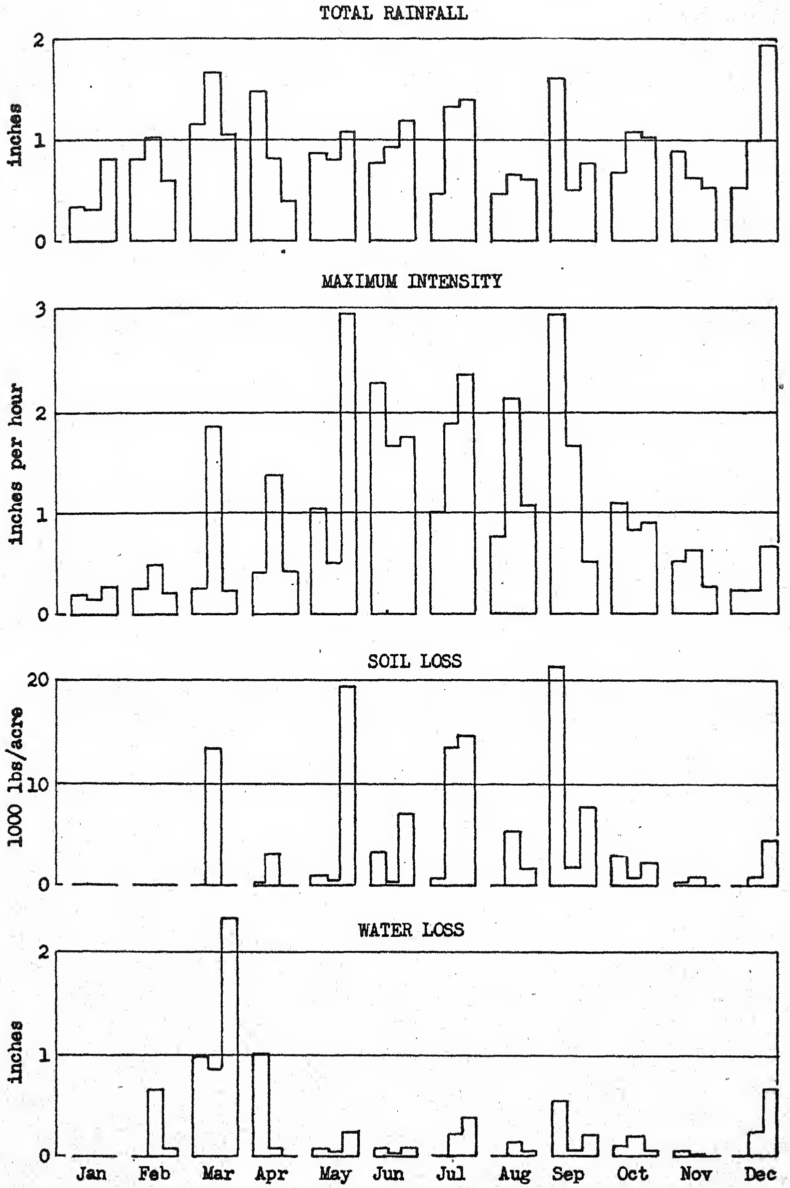


FIG. 4.—Total average rainfall by 10-day periods, highest 15-minute intensity during those periods, and average soil and water lost in runoff from fallow Honeoye silt loam, 18% slope, Marcellus, 1938 through 1942.

of rainfall during the periods the temperature is consistently below freezing, but the low frequency of excessive rains for November,

December, March, and April indicates that no such rains occurred in midwinter. None occurred during midwinter at the three locations where the erosion studies were made.

Thirty-five excessive rainstorms, as defined in Table 1, have caused 79% of the soil loss at the Arnot erosion station. Thirty-four occurred June 4 through September 4 and one October 23. During the same period, the Weather Bureau station at Ithaca, elevation approximately 900 feet, recorded 22 rains as excessive, and the highest intensity per 15-minute period was 3.24 inches per hour. Four storms exceeded that intensity at the Arnot station, two of which reached 4.64 inches per hour.

TABLE 1.—*Number of excessive rainstorms in New York by months through 1937.**

Location	Start record year	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
Buffalo	1905	—	1	4	11	11	14	9	—	—	—	50
Rochester	1905	—	—	5	15	12	13	7	1	—	—	53
Oswego	1908	—	—	7	7	13	9	8	3	—	—	47
Canton	1906	—	—	3	15	19	16	7	—	—	—	60
Syracuse	1903	—	—	3	15	22	15	5	2	—	—	62
Ithaca	1908	—	—	5	14	22	14	7	2	—	—	64
Binghamton	1905	—	—	10	11	17	12	11	2	1	—	64
Albany	1905	—	—	6	10	19	16	9	1	—	—	61
New York	1905	1	1	5	12	18	15	12	4	—	1	69
Total per month		1	2	48	110	153	124	75	15	1	1	530
% total each month		—	—	9	21	29	23	14	3	—	—	

*The Weather Bureau describes an excessive rain as the accumulated amounts of precipitation for each 5 minutes during all storms in which the rate of fall equaled or exceeded 0.25 inch in any 5-minute period, or 0.30 inch in any 10-minute period, or 0.35 inch in any 15-minute period, etc. The data presented here are derived from Climatic Summary of the United States to 1930, Sections 80, 81, 82, and U. S. Dept. Agr. Weather Bureau; Report of the Chief of the Weather Bureau, 1931–32, 1932–33, 1934–35, U. S. Dept. Agriculture; and U. S. Meteorological Yearbook, 1935, 1936, 1937, U. S. Dept. Agriculture.

DISCUSSION

Erosion measurements from fallow land at three locations in New York have indicated that there are two critical periods during the year when precautions should be taken to protect fields where erosion is likely to occur. These are the winter, chiefly late winter when there is little or no snow cover, and during the summer thunderstorm period. With rare exceptions, after the frost leaves the ground in early spring the chance of erosive rains occurring is slight before the first of June. There is good opportunity for early sown grains planted on the contour to become established and furnish soil protection before the high intensity rain storms occur. It is obvious that where it is necessary to leave sloping land exposed to the beating action of rain drops during the summer season, as in seed-bed preparation or growth of intertilled crops, proper erosion control measures should be carried out. These may consist of simple pre-

cautions, such as maintaining the active organic matter of the soil, contour cultivation, surface litter or rough tillage, or as the erosion risks increase, they may become increasingly complex, involving the use of strip cropping and diversion ditches.

It is evident from the data presented that late fall plowed land presents no serious erosion hazard provided reasonable precautions are followed. The dangerous periods are when alternate freezing and thawing occurs in late winter or early spring. At the higher elevations the transition from winter to spring is comparatively short compared to lower elevations, and at both elevations the south and southwest slopes present the greater risk. On these slope aspects fall plowing should be in contour strips, increasing the width of the strips as the erosion hazard decreases. It is especially important that plowed land be left rough and not smoothed over. The rough clods or sods catch the snow and the snow insulates the soil against freezing. Even after a cold winter, the soil under the deeper pockets may be unfrozen and able to absorb water from the melting snow. These pockets form absorption centers that save water which may be needed later.

SUMMARY

A study of soil erosion from fallow land in relation to rainfall intensities was made in three agricultural areas of New York over a period of 5 to 8 years. At each location major soil losses were caused by the high intensity rains. With few exceptions these rains occurred during the warm months, June through September. Late winter and early spring losses, especially at lower elevations, were severe only on south and southwest slopes insufficiently protected by snow and exposed to periods of alternate freezing and thawing. The two periods of erosion hazard, June through September and during the late winter and spring, are clearly defined and offer a guide for the use of erosion control practices.

LITERATURE CITED

1. Anderson, Alfred B. O., Fletcher, Joel E., and Edlefsen, N. E. Soil-moisture conditions and phenomena in frozen soils. Trans. Amer. Geophys. Union, Part 11:356–364. 1942.
2. Blumenstock, David I. Rainfall characteristics as related to soil erosion. U.S.D.A. Tech. Bul. 698. 1939.
3. Borst, H. L., and Woodburn, R. The effect of mulching and methods of cultivation on runoff and erosion from Muskingum silt loam. Agr. Eng., 23:19. 1942.
4. Laws, J. O. Recent studies in raindrops and erosion. Agr. Eng., 21:431. 1940.
5. Neal, J. H. Effect of degree of slope and rainfall characteristics on runoff and soil erosion. Agr. Eng., 19:213–217. 1938.
6. Palmer, V. J., and Free, G. R. Operation of a portable rainfall simulator, and relative infiltration and soil loss data for certain soils in New York, Georgia, North Carolina, and Ohio. Unpublished report. 1939.
7. Yarnell, David L. Rainfall intensity-frequency data. U.S.D.A. Misc. Pub. 204. 1935.

AVAILABILITY OF ROCK AND OTHER PHOSPHATE FERTILIZERS AS INFLUENCED BY LIME AND FORM OF NITROGEN FERTILIZER[1]

GARTH W. VOLK[2]

THE availability to plants of soil phosphorus and that in phosphatic fertilizers is related to the pH of the soil. Many reports in the literature indicate that phosphorus in rock phosphate is more available to plants in acid soils than in neutral or alkaline soils (1, 2, 3, 4, 6).[3] Therefore, it would appear that the use of an acid-forming nitrogenous fertilizer, such as ammonium sulfate, would increase the availability of the phosphorus in the more insoluble phosphatic fertilizers. Since large amounts of ammonium sulfate and urea are used in mixed fertilizers, this study was conducted to determine their possible effect on the availability of phosphorus in the more insoluble forms.

EXPERIMENTAL PROCEDURE

Greenhouse tests were conducted with Cecil and Eutaw clays and Norfolk sandy loam. These soils were placed in 2-gallon pots, one-half of which, in the case of each soil, being then treated with nitrate of soda and the other half with ammonium sulfate. Both superphosphate and rock phosphate were used with the two sources of nitrogen. All fertilizers applied to a given pot were thoroughly mixed before being added to the soil. The indicator crops grown were sorghum and flax and the yields were recorded as grams of dry weight of plants.

A second series of greenhouse tests was run in which Hartsell fine sandy loam, Norfolk sandy loam, and Cecil clay were used. The sources of nitrogen were nitrate of soda, ammonium sulfate, and urea. Superphosphate, Tennessee brown rock phosphate, waste pond phosphate, fused rock phosphate, and calcium metaphosphate were used with each of the three nitrogenous fertilizers. In the case of each soil, one third of the pots did not receive lime, one-third received 1 ton of lime per acre thoroughly mixed throughout the soil, and the remaining pots received lime mixed with the fertilizer before application to the soil. When lime was mixed with the fertilizer, only enough lime was used to neutralize the acidity of the nitrogenous fertilizer, and in the case of nitrate of soda lime was used at the same rate as for ammonium sulfate. All fertilizers used were thoroughly mixed before adding them to the soil. The fertilizer mixture was then mixed with about 12% of the soil in the pot, and placed in a layer at a depth of 2 inches. Each pot received 1 gram of gypsum. Sorghum and oats were grown, the dry weights recorded, and the plant material analyzed for total calcium and phosphorus. The pH of the soil was determined before and after each crop.

---

[1]Contribution from the Department of Agronomy and Soils, Alabama Agricultural Experiment Station, Auburn, Ala. Published with the approval of the Director. Received for publication June 21, 1943.

[2]Soil Chemist.

[3]Reference by numbers in parenthesis is to "Literature Cited", p. 56.

RESULTS AND DISCUSSION

EFFECT OF NITROGENOUS FERTILIZER ON PHOSPHATE AVAILABILITY AS SHOWN BY CROP RESPONSE

The results of the first series of experiments (Table 1) show the effect of nitrate of soda and ammonium sulfate when used with either superphosphate or rock phosphate on the growth of sorghum. When ammonium sulfate was used with superphosphate, considerably more sorghum was produced on Eutaw clay than when nitrate of soda was used. The yields with the different nitrogen sources were about the same on Cecil clay. Ammonium sulfate on Norfolk sandy loam greatly reduced the yield. This probably was due to the fact that the soil acidity was greatly increased by this acid-forming fertilizer. The pH values of the other soils were not greatly affected because of their higher buffer capacity. When ammonium sulfate and rock phosphate were used on Eutaw and Cecil clays, the yields were increased approximately two to four times over the nitrate of soda and rock phosphate combinations. When flax was grown, the yields were very low and indicated that this crop requires large amounts of available P_2O_5 (Table 2). The results, however, have the same trend as for sorghum, except on the Norfolk soil.

TABLE 1.—*Yields of sorghum grown on Eutaw, Norfolk, and Cecil soils treated with various combinations of nitrogenous and phosphatic fertilizers.*

Fertilizers used	Pounds P_2O_5 added per acre	Yield of sorghum in grams dry weight			pH of soil after sorghum crop*		
		Eutaw clay	Norfolk sandy loam	Cecil clay	Eutaw clay	Norfolk sandy loam	Cecil clay
$NaNO_3$, gypsum	0	6.5	30.0	2.0	4.8	5.9	5.4
Superphosphate, $NaNO_3$	72	47.0	56.5	32.0	5.7	6.5	6.3
Superphosphate, $(NH_4)_2SO_4$	72	66.0	4.5	33.5	5.0	4.1	4.9
Superphosphate, $NaNO_3$	96	60.0	57.0	49.5	5.7	6.5	6.5
Superphosphate, $(NH_4)_2SO_4$	96	76.5	10.5	45.0	4.9	4.2	5.1
Superphosphate, $NaNO_3$	384	92.5	65.0	68.5	5.3	6.1	6.1
Rock phosphate, $NaNO_3$, gypsum	72	16.0	26.0	6.5	4.8	6.3	5.2
Rock phosphate, $(NH_4)_2SO_4$	72	30.0	6.5	22.5	4.7	4.2	4.7
Rock phosphate, $NaNO_3$, gypsum	96	17.0	31.0	5.5	4.7	6.4	5.3
Rock phosphate, $(NH_4)_2SO_4$	96	38.0	8.0	22.5	4.6	4.1	4.6
Rock phosphate, $NaNO_3$, gypsum	384	24.0	50.0	10.0	4.8	6.5	5.3
Rock phosphate, $(NH_4)_2SO_4$	384	62.5	4.5	31.0	4.8	4.1	4.8

*KCL added at the rate of 150 pounds per acre to all pots. Nitrogen added at the rate of 72 pounds per acre of N. The pH of soils before treatment, Eutaw: 4.8; Norfolk, 5.8; Cecil, 5.5.

TABLE 2.—*Yields of flax grown on Eutaw, Norfolk, and Cecil soils treated with various combinations of nitrogenous and phosphatic fertilizers.*

Fertilizer used*	Pounds P_2O_5 added per acre	Yields of flax in grams of dry weight		
		Eutaw clay	Norfolk sandy loam	Cecil clay
$NaNO_3$, gypsum	0	1.25	0.85	0.40
Superphosphate, $NaNO_3$	72	3.60	2.35	4.45
Superphosphate, $(NH_4)_2SO_4$	72	4.50	4.05	5.65
Superphosphate, $NaNO_3$	96	4.30	3.95	4.50
Superphosphate, $(NH_4)_2SO_4$	96	6.25	4.40	6.20
Superphosphate, $NaNO_3$	384	12.60	5.10	10.35
Rock phosphate, $NaNO_3$, gypsum	72	1.85	0.85	0.95
Rock phosphate, $(NH_4)_2SO_4$	72	1.90	1.60	1.90
Rock phosphate, $NaNO_3$, gypsum	96	1.60	1.20	1.10
Rock phosphate, $(NH_4)_2SO_4$	96	2.25	1.30	1.85
Rock phosphate, $NaNO_3$ gypsum	384	1.95	0.70	1.40
Rock phosphate, $(NH_4)_2SO_4$	384	2.90	0.85	2.65

*KCL added to all pots at the rate of 150 pounds per acre. Nitrogen applied at the rate of 72 pounds per acre of N.

TABLE 3.—*Yields of sorghum grown on Cecil clay treated with various combinations of phosphatic and nitrogenous fertilizers and lime.**

Phosphate used	Sorghum yields in grams of dry weight and pH of soils after treatment					
	$NaNO_3$		$(NH_4)_2SO_4$		Urea	
	Yield	pH	Yield	pH	Yield	pH
			No Lime			
None	3.9	5.6	6.8	5.3	2.8	5.2
Superphosphate	48.6	5.8	54.6	5.2	43.5	5.6
Rock phosphate	17.1	6.0	35.1	5.4	24.2	5.5
Waste pond phosphate	14.5	5.7	23.8	5.6	23.1	5.3
Calcium metaphosphate	58.8	6.0	57.0	5.2	56.0	5.5
Fused rock phosphate	46.2	5.7	55.5	5.2	44.3	5.6
			Lime Mixed With Soil†			
Superphosphate	51.9	6.1	58.0	5.5	59.5	6.1
Rock phosphate	6.7	6.1	30.9	5.7	12.2	6.0
Waste pond phosphate	7.4	6.2	13.8	5.7	11.3	5.7
Calcium metaphosphate	60.5	6.2	60.5	5.8	51.8	5.9
Fused rock phosphate	44.9	5.9	51.4	6.0	44.1	5.9
			Lime Mixed With Fertilizer‡			
Superphosphate	48.4	5.9	61.3	5.3	54.1	5.6
Rock phosphate	6.9	5.8	9.2	5.3	6.1	5.4
Waste pond phosphate	8.2	5.5	13.0	5.3	5.5	5.4
Calcium metaphosphate	42.7	6.1	66.4	5.3	52.0	5.5
Fused rock phosphate	45.9	5.8	49.2	5.4	42.7	5.4

*$CaSO_4$ and KCL added to all pots. Phosphate was applied at the rate of 96 pounds per acre of P_2O_5. Nitrogen was applied at the rate of 72 pounds per acre of N. The soil had a pH of 5.7 before treatment.

†1 ton of lime per acre.

‡Enough lime used to neutralize nitrogenous fertilizers and in case of $NaNO_3$ the same amount as used for $(NH_4)_2SO_4$.

Results from the second series of experiments (Tables 3 and 4) are given for the Cecil clay only, because those obtained from the Norfolk and Hartsells soils were similar to those for Cecil. Where no lime was used variations from the general trend did occur which will be pointed out. When ammonium sulfate or urea were used in place of nitrate of soda with either rock or waste pond phosphate, the yield of sorghum and oats was greatly increased when no lime was applied. When lime was mixed with the soil the same fact held true, but, when lime was mixed with the fertilizer before application to the soil there were no significant variations in the yields due to the form of nitrogen.

TABLE 4.—*Yields of oats grown on Cecil clay treated with various combinations of phosphatic and nitrogenous fertilizers and lime.**

Phosphates used	pH of soils after treatment and oat yields in grams of dry weight					
	$NaNO_3$		$(NH_4)_2SO_4$		Urea	
	Yield	pH	Yield	pH	Yield	pH
No Lime						
None	1.8	5.5	5.9	4.8	1.9	4.9
Superphosphate	27.2	5.7	26.8	5.0	27.4	5.4
Rock phosphate	9.5	5.9	16.8	5.1	15.6	5.6
Waste pond phosphate	7.2	5.9	12.9	5.4	12.0	5.4
Calcium metaphosphate	24.7	5.8	23.1	5.1	24.8	5.5
Fused rock phosphate	21.2	6.2	24.5	5.1	21.3	5.4
Lime Mixed With Soil†						
Superphosphate	27.4	6.3	27.4	5.5	26.2	6.1
Rock phosphate	4.9	6.1	14.4	5.8	14.7	6.0
Waste pond phosphate	5.1	6.1	11.4	5.7	9.7	5.9
Calcium metaphosphate	23.8	6.4	25.7	5.8	22.7	6.0
Fused rock phosphate	19.7	6.4	24.8	5.8	20.9	6.3
Lime Mixed With Fertilizer‡						
Superphosphate	27.8	5.9	26.9	5.5	25.0	5.8
Rock phosphate	2.1	5.8	6.4	5.5	4.8	5.6
Waste pond phosphate	2.4	5.8	7.7	5.4	3.2	5.2
Calcium metaphosphate	27.9	6.1	27.2	5.4	24.3	5.5
Fused rock phosphate	20.5	6.3	25.1	5.3	22.0	5.9

*$CaSO_4$ and KCL added to all pots. Phosphate was applied at the rate of 96 pounds per acre of P_2O_5. Nitrogen was applied at the rate of 72 pounds per acre of N.
†1 ton of lime per acre.
‡Enough lime used to neutralize nitrogen fertilizers and in the case of $NaNO_3$ the same amount as for $(NH_4)_2SO_4$.

The pH of the Cecil clay (Table 3) was reduced from 5.7 to 5.3 by ammonium sulfate when no lime was used or when lime was mixed with the fertilizer; however, when lime was mixed with the soil, the pH did not change appreciably. Urea caused a reduction of 0.3 pH when lime was not used, but there was no appreciable change when lime was mixed with the soil or the fertilizer made non-acid forming. Ammonium sulfate caused the acidity of the soil to

increase an additional 0.2 pH after the second application of fertilizer was made for the oat crop. In the case of the Norfolk and Hartsells soils the acidity was increased by about 0.8 pH (data not included) when the acid-forming nitrogenous fertilizers were used in the absence of lime. This reduction in pH was accompanied by a reduction in the yield of sorghum and oats. Nitrate of soda in the absence of lime did not affect the pH of any of the soils used.

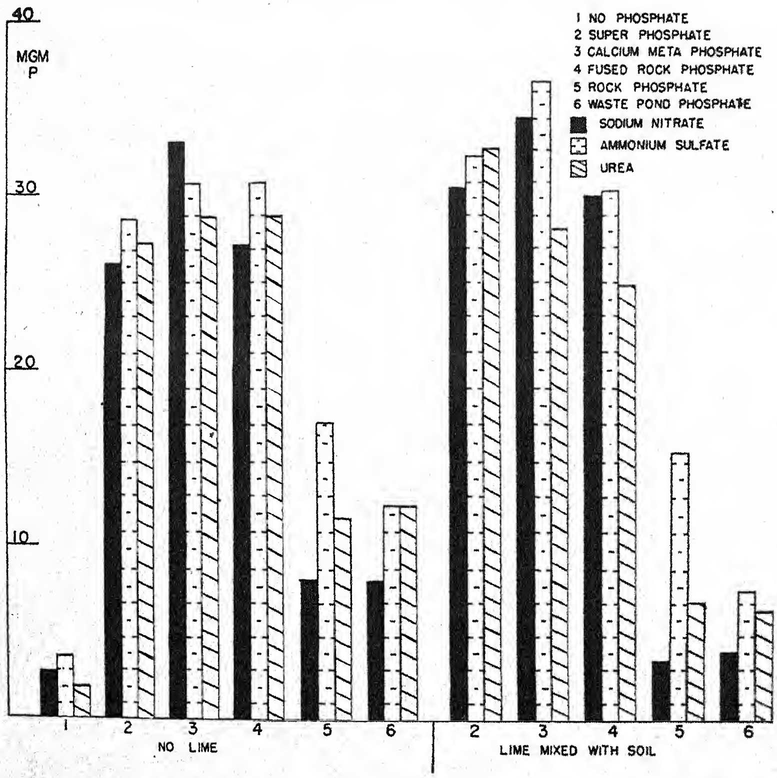


FIG. 1.—The total milligrams of phosphorus removed by sorghum from limed and unlimed Cecil clay treated with various kinds of phosphatic and nitrogenous fertilizers.

It appears that the use of acid-forming nitrogenous fertilizer with the more insoluble phosphates increased the availability of the phosphorus in these materials. The apparent solvent effect of the nitrogenous fertilizers is not reduced appreciably when the soil is limed, but when the lime is mixed with the fertilizer the acid formed from the nitrogenous fertilizers is neutralized before it can increase the availability of the phosphorus in the more insoluble phosphates. Even though the effectiveness of rock and waste pond phosphate was increased, these phosphates produced less than 65% as much sorghum and oats as did the superphosphate.

EFFECT OF NITROGENOUS FERTILIZER ON UPTAKE OF CALCIUM AND PHOSPHORUS

The crops from the second series of experiments were analyzed for phosphorus and calcium and the results, expressed as total milligrams per pot, are given in Figs. 1, 2, 3, and 4. From soils receiving rock or waste pond phosphate without lime considerably more phosphorus was removed by plants when ammonium sulfate

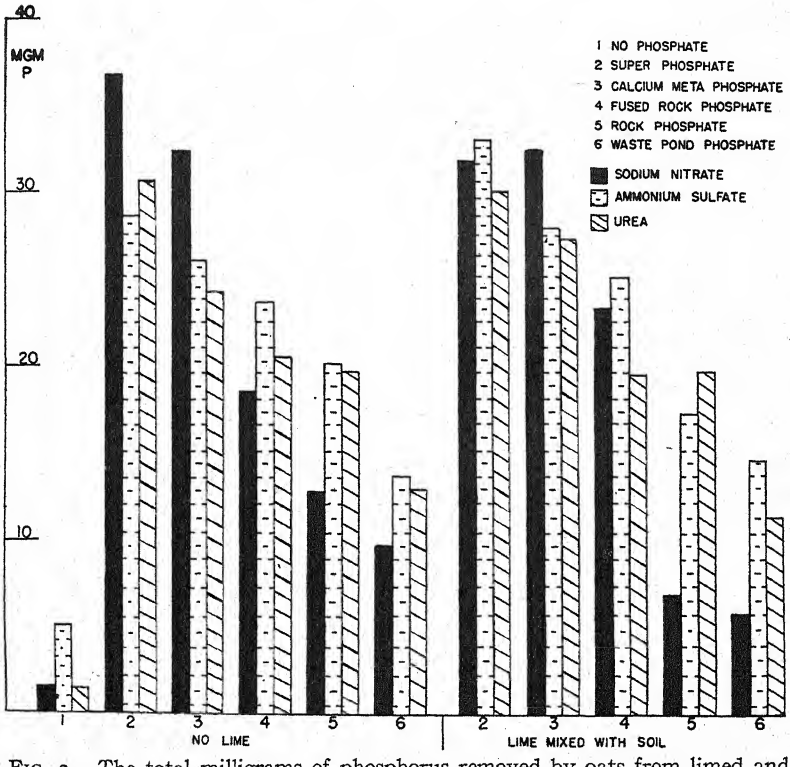


FIG. 2.—The total milligrams of phosphorus removed by oats from limed and unlimed Cecil clay treated with various kinds of phosphatic and nitrogenous fertilizers.

or urea were applied than when nitrate of soda was used. The addition of lime to the soil or to the fertilizer did not change this relationship (Fig. 5). Similar results were secured with ammonium sulfate and nitrate of soda when fused rock phosphate was used as the source of phosphorus; with urea, however, the amount of phosphorus removed dropped slightly below that for nitrate of soda on the limed soil and increased slightly on the unlimed soil. The same general trends prevailed in the case of Norfolk and Hartsells soils. These data again substantiate the conclusion, based on crop response, that the use of acid-forming nitrogenous fertilizers increases the availability of phosphorus in the more insoluble forms.

The total amount of calcium (Fig. 3) taken up by sorghum was only slightly greater for ammonium sulfate than for nitrate of soda or urea. Oats, however, removed considerably more calcium from the soil when ammonium sulfate or urea were used with the various sources of phosphorus than when nitrate of soda was the source of nitrogen (Fig. 4).

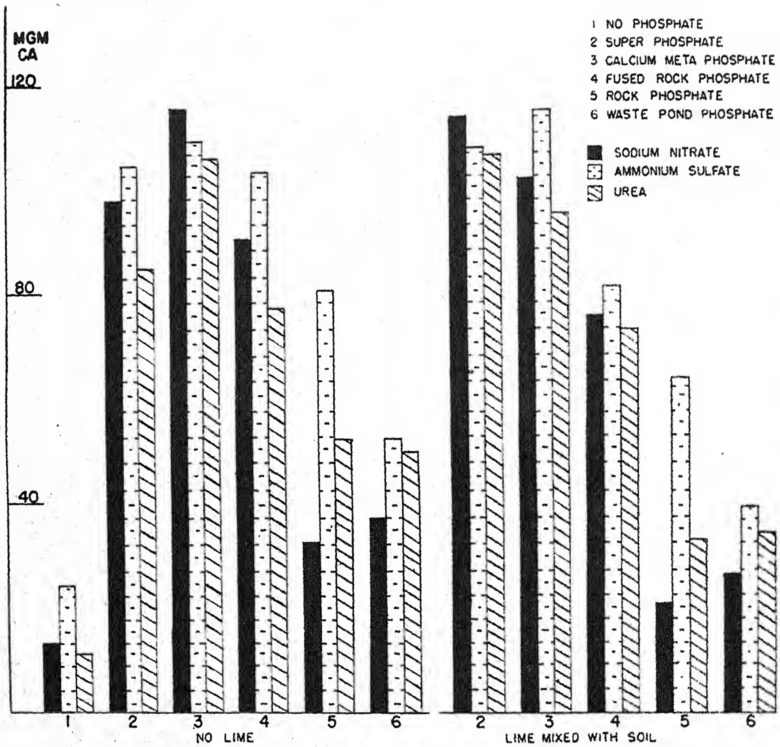


FIG. 3.—The total milligrams of calcium removed by sorghum from limed and unlimed Cecil clay treated with various kinds of phosphatic and nitrogenous fertilizers.

Figs. 5 and 6 indicate the total phosphorus and calcium uptake by sorghum and oats grown on Cecil clay treated with either rock or waste pond phosphate and various nitrogenous fertilizers and soil treatments. In general, lime mixed with the fertilizer had a depressing effect on the uptake of calcium and phosphorus when ammonium sulfate or urea were the source of nitrogen. This indicates that the lime mixed with the fertilizer neutralized any effect the acid-forming nitrogenous fertilizers may have had on the phosphates. This depression was not found when the more soluble phosphates were used.

Ca:P RATIO IN OATS AND SORGHUM

The percentage composition ratios of calcium and phosphorus in sorghum and oats are given in Table 5. When nitrate of soda

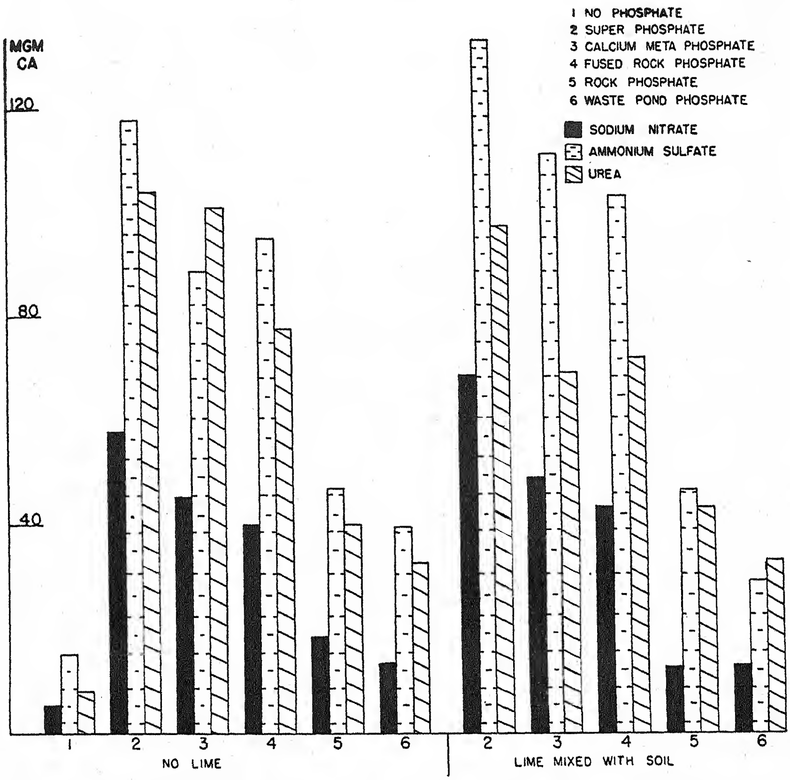


FIG. 4.—The total milligrams of calcium removed by oats from limed and unlimed Cecil clay treated with various kinds of phosphatic and nitrogenous fertilizers.

TABLE 5.—*A comparison of the ratio of Ca to P in oats and sorghum when grown on soil treated with superphosphate and various nitrogenous fertilizers.*

Lime treatment	Ca:P ratio in					
	Oats			Sorghum		
	$NaNO_3$	$(NH_4)_2SO_4$	Urea	$NaNO_3$	$(NH_4)_2SO_4$	Urea
Cecil Clay						
None	1.6	4.1	3.4	3.7	3.7	3.1
Lime mixed with soil	2.2	4.1	3.2	3.7	3.3	3.3
Lime mixed with fertilizer	1.9	4.3	3.2	3.4	3.4	3.6
Norfolk Fine Sandy Loam						
None	1.3	2.9	3.7	3.7	4.4	4.8
Lime mixed with soil	1.3	2.0	2.3	2.6	4.0	3.8
Lime mixed with fertilizer	1.1	2.2	3.0	1.9	3.6	4.2

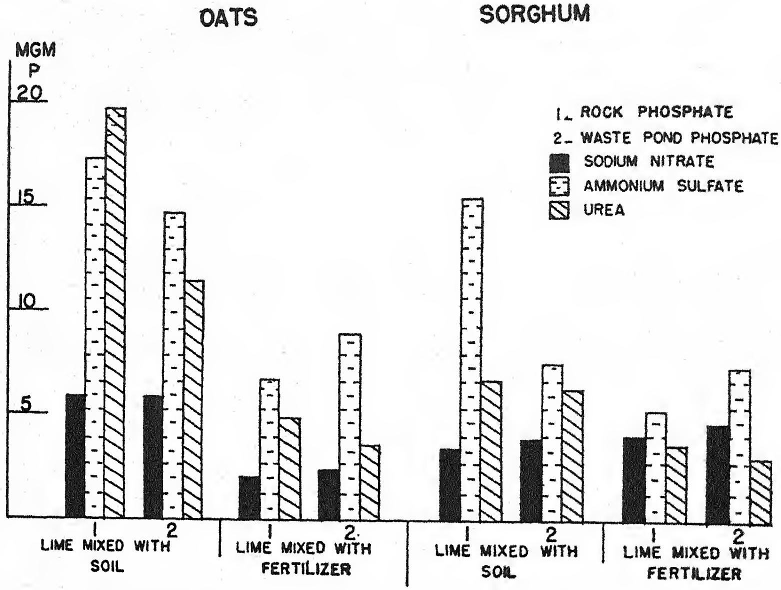


FIG. 5.—The total milligrams of phosphorus removed from Cecil clay treated with rock and waste pond phosphatic and various nitrogenous fertilizers.

was used with superphosphate, the Ca:P ratio in oats was approximately one half as high as that when ammonium sulfate or urea was used. This was found to be true with all of the different kinds

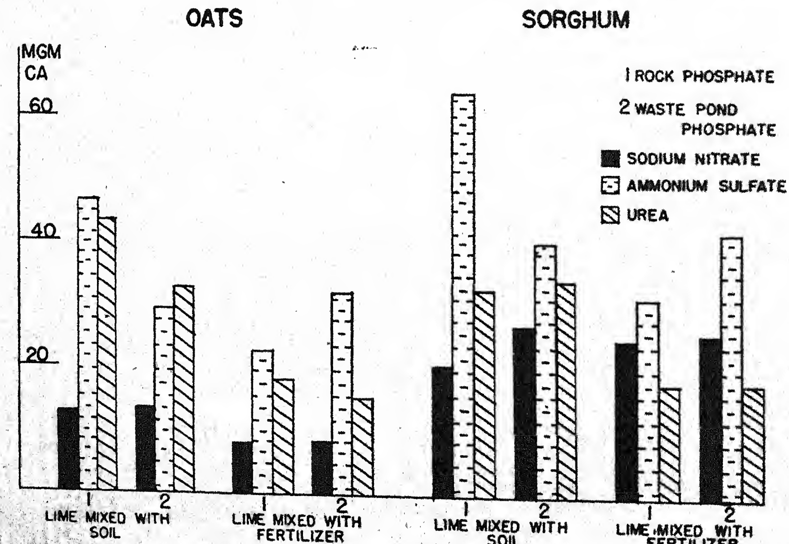


FIG. 6.—The total milligrams of calcium removed from Cecil clay treated with rock and waste pond phosphatic and various nitrogenous fertilizers.

of phosphate used. In the case of the more soluble phosphates the yields of oats and sorghum and the total amount of phosphorus removed by these crops were about the same for all nitrogenous fertilizers. The total amount of calcium removed from the soil by oats, however, was considerably lower when nitrate of soda was used. This was not the case with sorghum.

These results substantiate those of Itallic (5) in which he reports that when sodium is absorbed by oats there is a compensating decrease in the absorption of K, Ca, and Mg. In the experiments reported the use of sodium nitrate caused a decrease in the calcium content of the oat plant, but did not reduce the phosphorus content; therefore, the Ca:P ratio dropped. This fact may be of importance in animal nutrition when nitrogenous fertilizers with or without sodium are used on crops grown for feed. Plants which do not readily absorb sodium apparently do not have the absorption of calcium greatly affected. This may be true with sorghum because its Ca:P ratio either did not change or dropped only slightly when sodium nitrate was used.

A COMPARISON OF PHOSPHATE FERTILIZERS

The yields of oats and sorghum and the total calcium and phosphorus absorbed by the plants indicate that, on the soils used, there is very little difference between the effectiveness of superphosphate or calcium metaphosphate as a fertilizer for these crops. Fused rock phosphate was slightly inferior to superphosphate and calcium metaphosphate, while ordinary rock and waste pond phosphate were greatly inferior under the conditions of the experiment. Even when the latter two were used with an acid-forming nitrogenous fertilizer they fell far below the more soluble phosphates.

SUMMARY AND CONCLUSIONS

Greenhouse experiments were conducted to determine the relative effect of various sources of nitrogen on the availability of the phosphorus in rock phosphate, waste pond phosphate, calcium metaphosphate, and superphosphate. The soils used were Cecil and Eutaw clays and Hartsells and Norfolk sandy loams. Various nitrogenous fertilizers were applied to unlimed and limed soils, and in other cases lime was mixed with the fertilizer before application to the soil. The results may be summarized as follows:

1. On unlimed and limed Cecil clay the use of ammonium sulfate or urea with rock and waste pond phosphate greatly increased the yield of sorghum and oats over that resulting from the use of sodium nitrate. When the lime was mixed with the fertilizer before application to the soil, these increases were not obtained.

2. Even though the yields of sorghum and oats were greatly increased by using acid-forming nitrogenous fertilizers with the more insoluble phosphates, the yields were still much lower than those obtained with superphosphate.

3. The use of ammonium sulfate or urea with the more insoluble phosphates increased the uptake of phosphorus and calcium by sorghum and oats grown on both unlimed and limed soils.

4. The Ca:P ratio in oats fertilized with ammonium sulfate or urea was about twice as high as the ratio in oats fertilized with sodium nitrate. Sodium nitrate decidedly reduced the total uptake of calcium by oats, but did not affect the uptake of phosphorus appreciably.

5. Superphosphate and calcium metaphosphate were the best phosphate fertilizers for oats and sorghum, fused rock phosphate was almost as good as the former two, and ordinary rock and waste pond phosphate were decidedly inferior.

LITERATURE CITED

1. AMES, J. W., and KITSUTA, K. Availability of rock phosphate as indicated by phosphorus assimilation of plants. Jour. Amer. Soc. Agron., 24:103–122. 1932.
2. FRAPS, G. S. Availability of the phosphoric acid of finely divided rock phosphate. Tex. Agr. Exp. Sta. Bul. 509. 1935.
3. GISIGER, L. Beitrag Zur Kenntnis der Wirkung des Knochenmehls and Thomasmehls. Bodenk. u. Pflanzenernähr, 16(3/4):210–229. 1940.
4. HARTWELL, B. L. The comparative value of different sources of phosphorus. R. I. Agr. Exp. Sta. Bul. 163. 1915.
5. ITALLIC, TH. B. VAN. The role of sodium in the kation balance of different plants. Trans. 3rd Int. Cong. Soil Sci. 1:191–4. 1935.
6. SCHMITT, L. Die Wirkung and Nachwirkung des Knochenmehls in irhrer Ablangigheit von dem Kalkzustand des Bodens. Bodenk. u. Pflanzenernähr., 18 (5/16):370–376. 1940.

HYBRID VIGOR IN BARLEY[1]

C. A. Suneson and O. C. Riddle[2]

STUDIES of heterosis in self-fertilized crops have been hampered by the difficulty of producing adequate populations for testing. The problem in barley is now somewhat simplified by the recent discovery of a male-sterile mutant[3] which can be utilized in making hybrids and in evaluating their performance. This report seeks primarily to call attention to these possibilities.

MATERIALS AND METHODS

The male-sterile mutant in barley is abnormal only in its lack of functional male flower parts, which condition is governed by a simple recessive character. For the studies herein reported two seed stocks were used. Thus, for yield comparisons, a homozygous fertile stock was required, while for crossing, a back-crossed population giving half male-sterile plants was used. Within this segregating stock it is not yet possible to distinguish between heterozygous fertile plants and the homozygous sterile types until flowering begins. Consequently, it is necessary to rogue out the fertile plants before they have shed pollen or to bag individual spikes on sterile plants before the lemma and palea have spread to permit entry of pollen in order to prevent sib crossing.

The hybrids herein considered were produced in isolated crossing plots. In 1939 alternate male and female rows were grown 12 inches apart and crosses effected by air movement of pollen. The percentage of florets setting seed was generally too low to be practical, however. Hence, in 1940 and 1941 spikes of the desired pollen parent were collected, clipped to encourage the anthers to "crawl", and then brushed against the open flower-protecting glumes of male-sterile spikes. This technic results in production of seeds on practically all florets.[4] Obviously, the labor requirement in producing hybrid seeds by this method is only a small fraction of that required when individual floret emasculation and pollination is necessary.

All comparisons between hybrids and parents were made from three-row plots with 16-foot rows spaced 12 inches apart, from which center rows were harvested for yield. The 1940 plantings involved 2-inch spacing of hybrid and parent seeds in triplicated Latin squares; whereas those in 1941 and 1942 involved 4-inch seed spacing in the rows for comparisons between randomized paired plots of the pollen parents and their progeny, each grown in quadruplicate. Gophers damaged the 1941 plantings so they were not harvested.

---

[1]Contribution from the Division of Cereal Crops and Diseases, Bureau of Plant Industry, Soils, and Agricultural Engineering, Agricultural Research Administration, U. S. Dept. of Agriculture, and the Department of Agronomy, University of California, Davis, Calif. cooperating. Received for publication June 28, 1943.

[2]Agronomist, Division of Cereal Crops and Diseases, and Associate in Agronomy, University of California, respectively.

[3]Suneson, C. A. A male sterile character in barley. Jour. Hered., 31:213–214. 1940.

[4]Riddle, O. C., and Suneson, C. A. Crossing studies with male-sterile barley. Jour. Amer. Soc. Agron., 36:62–65. 1944.

RESULTS

Tests in 1940, as presented in Table 1, showed significant differences in yield between two F_1 progeny and their parents, but not between the two different progeny. The increased yields of the F_1 progeny in this study were obviously not fully representative because of the high percentages of self-type (sib) plants in these populations. These resulted from failure to rogue often enough. A correction for this was attempted by using the border rows, arbitrarily choosing hybrid plants from one border row and substituting them in place of selfed types in the other row, from which the yield shown in the last column of Table 1 was computed. This technic is obviously faulty, but the results are indicative of even greater yield advantages for the F_1 progeny.

TABLE 1.—*Average performance of male parent, F_1 progeny, and the fertile form of the male parent, as determined during 1940 from triplicated nursery tests arranged in Latin squares at Davis, Calif.*

Variety or cross	C.I. No.*	Mean acre yield, bushels	Yield increase over mean of parents, %	S. E. diff., bushels	Sib crosses in population, %	Mean acre yield of pure F_1, bushels†
Wisconsin Barbless, ♂	5105	65.2				
F_1	—	87.9	32.2	5.9	22.7	98.3
Fertile, ♀	5368	67.7				
Atlas, ♂	4118	75.6				
F_1	—	91.0	28.5	3.8	21.8	99.4
Fertile, ♀	5368	66.0				

*C. I. refers to accession number of the Division of Cereal Crops and Diseases.
†Yield of one border row in which hybrid plants were arbitrarily substituted for sib plants.

The 1942 experiments reported in Table 2 were more extensive, but suffered from two limitations, i.e., poor plant survival, especially in certain parent plots, and inadequate sampling of the female parent. The higher plant survival of F_1 progeny, as compared to the parents, was no doubt a natural response from greater seed size and inherent vigor, however, for the hybrid plants were visually larger from the seedling stage through to maturity, as is evident for the Hannchen cross near maturity as shown in Fig. 1. Furthermore, normal compensatory tillering to correct for stand differences seems to have occurred in both hybrid and parent plots because the average acre yield of the five "adapted male parents" in Table 2 was only 1.5 bushels per acre below a comparable average from plantings of these varieties seeded at a rate of 55 pounds per acre.

The average yield of the female parent based on four plots distributed at random among all the others was definitely abnormal. This is the first time in 6 years of comparative testing that this selection has exceeded Atlas in yield. The range in variation between yields of the replicates was greater for this variety than for any other, suggesting that the yield reported for the female parent was greater than its true yield.

TABLE 2.—*Average performance of male parents and their F_1 progeny produced on male-sterile female plants as established from center row harvest of quadruplicated randomized pairs of three-row plots, 16 feet long and 12 inches between rows, in each of which 65 spaced seeds were sown at Davis, Calif., in 1942.*

Parent variety	C.I. No.	Av. kernel weight of seed planted, mg		Date headed		Av. height, in.		Selfed plants, %	Plants harvested, av. no. per row		Tillers harvested, av. no. per row		Av. kernel weight, mg		Av. yield per row, grams		Bushel weight, lbs.	
		P	F_1	P	F_1	P	F_1		P	F_1	P	F_1	P	F_1	P	F_1	P	F_1
Self-Fertile Form of Female Parent																		
Comp. Cross sel.	5368	46.6	—	Apr. 14	—	54	—	100.0	51	—	404	—	46.6	—	722.5	—	45.8	—
Unadapted Male Parents and Progeny																		
Hannchen	531	41.5	52.3	Apr. 20	Apr. 14	47	53	1.6	53	55	636	562	38.0	49.3	496.2	621.2	54.3	46.8
Wisconsin Barbless	5105	39.1	50.0	Apr. 15	Apr. 14	53	57	7.3	50	54	222	383	39.2	43.2	340.0	702.5	46.8	48.8
Adapted Male Parents and Progeny																		
Vaughn	1367	49.5	52.9	Apr. 10	Apr. 11	49	50	11.6	49	53	442	457	45.5	45.2	752.5	913.8	46.8	47.3
Hero	4602	48.8	53.9	Apr. 17	Apr. 15	50	51	5.5	50	55	357	436	48.6	45.2	665.0	862.5	46.5	47.3
Club Mariout	261	47.2	53.0	Apr. 18	Apr. 14	47	49	3.6	39	54	362	408	49.3	48.1	671.2	813.8	48.5	49.6
Atlas	4118	53.6	51.6	Apr. 14	Apr. 13	47	50	3.8	43	54	407	376	41.6	44.3	608.8	722.5	45.2	47.7
Coast (Tenn. Winter)	4633	42.4	46.0	Apr. 16	Apr. 15	46	50	5.1	51	50	354	371	39.2	42.4	616.2	711.2	48.4	48.4

Considering the whole experiment, however, the standard error of a variety mean yield was only 50.4 grams, or 7.4% of the general mean, and all estimates of error for other determinations (except for selfed plants) when related to their means had even lower coefficients of variability. By another approach, treating only the paired male and F_1 plots, the F_1 exceeded its male parent in yield in every paired planting, except for the hybrid with Coast (Tenn. Winter). Thus, there is evidence of heterosis in the F_1 populations and of differential combining ability among the male parents tested in 1942.

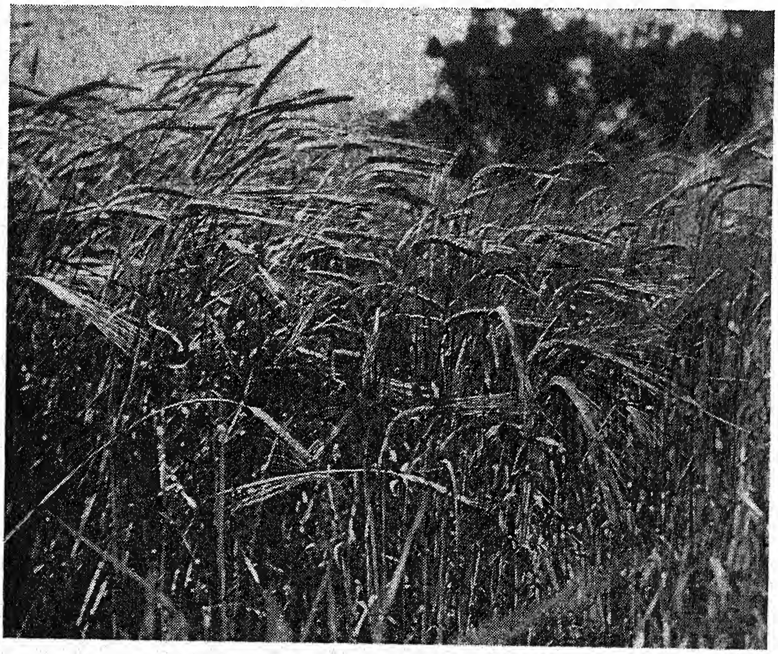


FIG. 1.—Plant size differences between F_1 hybrid (left) and Hannchen male parent (right).

In order to emphasize a pertinent difference, the data have been organized to differentiate between adapted and unadapted male parents. In the latter group the percentage increases in yield and other related responses for the progeny over the male parent were high, yet the total yield was considerably below that obtained when adapted male parents were used. In the case of Wisconsin Barbless this was not so evident in 1940 when this parent variety yielded relatively well. In the Hannchen cross, involving an interaction between the VV and vv factors, tillering and bushel weight were significantly lower in the F_1, but weight of seeds and yield were significantly higher. In the adapted parents group the F_1 progeny yielded in general proportion to the yield relationship of their parents, as was also shown by Immer.[5]

[5]IMMER, F. R. Relation between yielding ability and homozygosis in barley crosses. Jour. Amer. Soc. Agron. [illegible]

The commercial production of hybrid barley is quite obviously not yet feasible even though yield increases of more than 20% above the mean for the parents and other evidences of greater vigor have been rather consistently obtained. The methods used in this study might be successfully applied in effecting combinations between varieties and in evaluating such "inbred" varieties for breeding purposes, however.

SUMMARY

Male-sterile barley was used for the production of hybrid seeds by mass pollination technics. The F_1 progeny were subsequently tested for yield and other manifestations of heterosis. The seven different pollen parents crossed with male-sterile showed appreciable differences in combining ability with an average yield advantage over both parents of more than 20%. The experiments suggest a workable method of evaluating the yield transmitting qualities of varieties through tests of their F_1 hybrids.

CROSSING STUDIES WITH MALE-STERILE BARLEY[1]

O. C. RIDDLE AND C. A. SUNESON[2]

IN THE course of studies on fertility and crossability in a male-sterile barley[3] certain information has been compiled concerning the habits and adaptabilities of this particular barley as a plant breeding tool. Such information will be particularly useful as a background for understanding the diverse uses of this plant character which makes cross fertilization necessary in a normally self-fertilized species. Many of the crosses and backcrosses whose seed stocks were used for these studies were made for genetic, agronomic, or pathologic studies not herein considered.

EXPERIMENTAL RESULTS

LONGEVITY OF FERTILITY IN FEMALE FLOWERS

The length of the period of stigmatic receptivity to pollen was established for two different treatments—for plants under cheesecloth cages and for plants unprotected except for glassine bag coverings on the individual spikes. The spikes concerned were all tagged on April 17, 1940, on which date certain florets in the center of the spikes were beginning to open from action of the lodicules. Previous and subsequent experience has shown that structural development of the female flower parts in male-sterile plants is normal up to the time of flowering. Subsequently, the lodicules remain functional, never allowing the glumes to completely close, and actually reopening them widely each morning for several days. This reopening, as well as the period of stigmatic receptivity, is no doubt strongly influenced by temperatures and humidity. During the normal flowering season covered by these experiments, fertilization occurred during a period of 6 to 8 days following the first flower opening, as shown in Table 1. Pollinations in this case were made by hand on each individual floret of five randomly chosen spikes on each date and for each treatment. For the early pollinations, fertility tended to be highest in the top and central florets, while the last vestige of fertility was in the younger basal and lateral florets of the spikes.

VARIATIONS IN NATURAL CROSSING

In actual practice, both climatic and plant variations influence cross fertility. Three types of plant material are compared in Table 2 and the effects of two seasons shown. Alternate rows of the pollen parent variety and male-sterile, when grown in rows 12 inches apart, proved least efficient. This resulted in part from row spacing, but more particularly from seasonal difference in the heading date of

[1]Contribution from the Department of Agronomy, University of California, and the Division of Cereal Crops and Diseases, Bureau of Plant Industry, Soils, and Agricultural Engineering, Agricultural Research Administration, U. S. Dept. of Agriculture, cooperating. Received for publication June 28, 1943.

[2]Associate in Agronomy, University of California, and Agronomist, Division of Cereal Crops and Diseases, respectively.

[3]SUNESON, C. A. A male-sterile character in barley. Jour. Hered., 31:213–214. 1940.

TABLE 1.—*Average percentage seed set for groups of five spikes hand pollinated at 2-day intervals from 2 to 12 days after first flowering as determined under cheesecloth cages and in the open under glassine bags.*

Days from first flowering	Mean percentage seed set				Weather data	
	Under cloth cages		In open		Max. temp., °F	Min. temp., °F
	Lateral spikelets	Central spikelets	Lateral spikelets	Central spikelets		
2	83.5	85.8	84.6	73.1	83°	50°
4	89.1	77.3	84.6	64.2	80°	42°
6	69.3	54.1	66.2	50.9	70°	47°
8	—*	—*	—*	—*	67°	45°
10	9.9	6.5	0.8	0.0	63°	47°
12	0.6	0.0	0.0	0.0	72°	46°
14	0.0	0.0	0.0	0.0	79°	48°

*No pollinations because of rain.

similar varieties and from the stimulation of late tiller development of sterile plants when fertile plants were rogued from the row. Of further interest is the differential in crossing within Ms ms populations homozygous for all other characters, as compared with Ms ms backcross and F_2 populations heterozygous for other characters as well. This difference has been confirmed in numerous observations and probably results from height and maturity differences rather than a difference in pollen compatability.

TABLE 2.—*Annual variations in natural crossing on male sterile (ms ms) type plants at Davis, Calif.*

Year of test	Type of material	Florets setting seed on ms ms plants, %
1939	Alternate rows of pollen variety and ms ms	10.6
1939	Populations homozygous except for Ms ms gene	30.2
1942	Populations homozygous except for Ms ms gene	12.7
1939	Heterozygous backcross and F_2 populations	44.9
1942	Heterozygous backcross and F_2 populations	31.4

Cheesecloth cages played a rather prominent part in the 1940 experiments. Natural crossing under these conditions was not very high for on seven sterile plants paired with a like number of fertile plants, only 2% of the florets set seed. That this was more a function of poor facility for pollen distribution than any influence on the plant itself is suggested by comparison with those values shown in Tables 1 and 3 in which pollinations were facilitated by manual assistance.

COMPARISON OF POLLINATION METHODS

Comparisons designed to check the efficiency of pollinations made with bags and with pollen guns and to compare the weight of seeds produced by each method for both clipped and unclipped glumes are given in Table 3. Bag pollination involved (1) the covering of

spikes with glassine bags, (2) collection of pollen in a similar bag after clipping the glumes on a spike and allowing the anthers to dehisce, and (3) exchange of bag coverings accompanied by agitation to insure pollen distribution. The more violent application of pollen under force of air from a pollen gun was less effective and collection of pollen for this procedure was more difficult than with the bag method. More recently, direct brushing of a clipped pollen-bearing spike against a male-sterile spike at a receptive state has been proved to be the most effective method of making crosses. Clipping of glumes on male-sterile plants to facilitate pollen entry reduced seed size. The comparative appearance of a normal pollen parent spike before clipping and of a male-sterile spike at the receptive state is shown in Fig. 1.

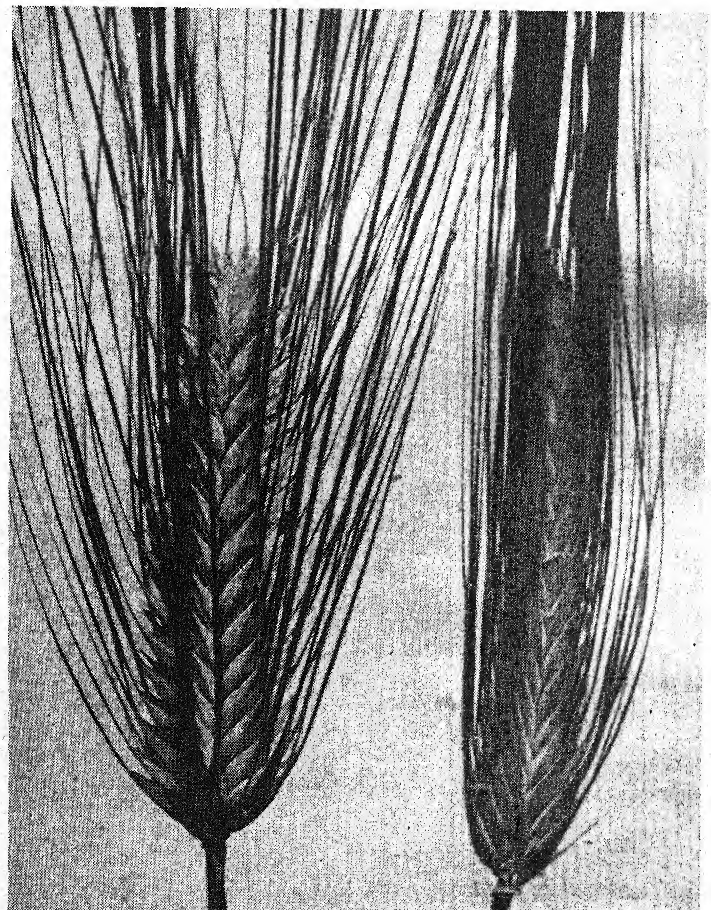


FIG. 1.—Comparative appearance of male-sterile head (left) and normal head (right) at the flowering stage.

TABLE 3.—*Comparison of methods of pollination and of prior treatment of female spikes of ms ms as related to seed set and kernel weight.*

No. of spikes	Manner of pollination	Clipped ♀		Unclipped ♀	
		Seed set, per cent	Kernel weight, mg	Seed set, per cent	Kernel weight, mg
14	Bag	74.4	3.16	—	—
15*	Bag	81.7	3.52	36.5	4.38
28*	Pollen gun	40.1	3.67	16.8	4.83
34	Spike contact	—	—	78.2	—

*Opposite sides of same spikes compared, i.e., clipped vs. unclipped.

RELATION OF SPIKE FERTILITY TO SEED SIZE

Inasmuch as spike fertility seems to affect seed size, a number of populations have been combined to compare the relationships between fertility classes and seed size as shown in Table 4. These are all from unclipped florets and mostly from highly heterogeneous populations. Whether as wide a range as this would obtain from homozygous populations is not known, but experience suggests that a very low seed set on a spike actually results in decreased seed size and that when about half the florets are fertilized maximum seed size results.

TABLE 4.—*Relation of spike fertility to kernel weight as determined from random sampling of various stocks of ms ms plants naturally cross pollinated.*

Fertile florets on spike, percentage classes	Number of kernels sampled	Av. kernel weight, mg
1–15	376	3.96
16–30	795	4.31
31–45	881	4.69
46–60	565	4.61
61–75	348	4.39
Over 76	803	3.60

SUMMARY

Factors relative to the use of a male-sterile barley stock are discussed, including crossing technics, fertile period for the female flowers, and certain causes of variation in the set of seed, together with the effects of such seed density differences on kernel weight. The information is particularly applicable to genetic, agronomic, and pathologic studies being conducted with this seed stock.

THE LOCATION OF TWO GENES FOR MATURE PLANT CHARACTERS IN BARLEY IN LINKAGE GROUP NO. 1[1]

D. W. ROBERTSON, F. R. IMMER, G. A. WIEBE, AND H. STEVENS[2]

THIS paper presents the results of a cooperative study of linkage relationships made by the Colorado Agricultural Experiment Station, the Minnesota Agricultural Experiment Station, and the Division of Cereal Crops and Diseases, Bureau of Plant Industry, Soils, and Agricultural Engineering, Agricultural Research Administration, U. S. Dept. of Agriculture.

LITERATURE REVIEW

The factor pair *Ee* for normal vs. long outer glume (10)[3] was studied by Bose, *et al.* (1).[3] They found a linkage of normal vs. long outer glume and non-six-row vs. six-row. The recombination value was 24.7%. The awnless vs. awned factor pair (*Lk lk*) (10) was described by Engledow (3) who found its expression to be markedly influenced by environment. He concluded in another paper (4) that, "the character 'six-row' and the character 'full awns' are governed by separate but highly linked factors."

Myler (8) found two factor pairs, *Lk lk* and Lk_1 lk_1, differentiating awn types in crosses between Awnless (C.I. 5631) and several different awned varieties.

Leonard (7) found another factor pair *Lr lr* for presence vs. absence of appendages on the lemma of the lateral florets to be linked with *Or or*, a factor pair from green vs. orange seedlings, with a recombination value of $38.58 \pm 1.20\%$.

Four other factor pairs (9, 10) have previously been located in Group I, namely, *Vv* for non-six-row vs. six-row and *Ff* for green vs. chlorina plant color, *Or or* for green vs. orange seedlings and *Yy* for green vs. virescent seedlings.

MATERIAL AND METHODS

The parent varieties carrying the genes used in these studies are Englawnless, C.I. 2505,[4] and Triple-bearded Mariout, C.I. 2523. Englawnless (Fig. 1) is a two-rowed barley without awns or appendages on the lemma of the central florets. This variety is similar in its response to environment to the variety Inerme described by Engledow (3). The inheritance of the awnless vs. fully awned character pair *Ll lk* can be explained on the basis of a simple Mendelian factor pair. There is, however, a slight excess of fully awned plants.

---

[1]Contribution from the Colorado Agricultural Experiment Station, the University of Minnesota, the Idaho Agricultural Experiment Station, and the Division of Cereal Crops and Diseases, Bureau of Plant Industry, Soils, and Agricultural Engineering, Agricultural Research Administration, U. S. Dept. of Agriculture, cooperating. Published with the approval of the Director of the Colorado Agricultural Experiment Station as Scientific Series Paper No. 167, Fort Collins, Colo., and the University of Minnesota as Scientific Series Paper No. 2092. Received for publication June 30, 1943.

[2]Agronomist, Colorado Agricultural Experiment Station, Fort Collins, Colo.; Professor of Plant Genetics, University of Minnesota; and Senior and Associate Agronomists, Division of Cereal Crops and Diseases, Bureau of Plant Industry, Soils, and Agricultural Engineering, U. S. Dept. of Agriculture, respectively.

[3]Numbers in parenthesis refer to "Literature Cited", p. 71.

[4]C.I. refers to accession number of the Division of Cereal Crops and Diseases.

Triple-bearded Mariout, C.I. 2523, is a six-rowed barley with broad, fully awned outer glumes (Fig. 2). The character is undoubtedly the same as the one described for Pusa barley, Type 1, by Bose, *et al.* (1). It is a simple Mendelian recessive, the factor pair for short vs. long outer glume being *Ee*.

Studies of the inheritance of short vs. long outer glume *Ee* were made at St. Paul, Minn.; Aberdeen, Idaho; and Fort Collins, Colo. The inheritance of the factor pair *Lk lk* was studied at Fort Collins, Colo., and Aberdeen, Idaho.

In studying the linkage of *Ee* and *Lk lk* with other factor pairs the recombination percentages were determined from F_2 and F_3 data by the use of Immer's (5, 6) tables and formulae and Collins' (2) formula.

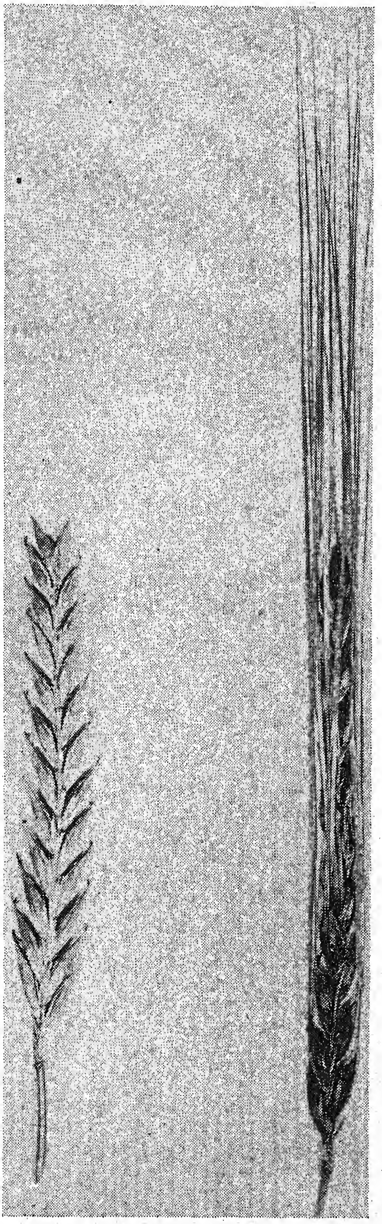


FIG. 1.—*Left*, awnless Englawnless; *right*, fully awned *H. def. nudideficiens*.

EXPERIMENTAL RESULTS

Table 1 gives the genetic constitution of the parental varieties for characters in chromosome I.

In Table 2 is given the F_2 data from the various crosses made to study linkage of *Ee* and *Lk lk* with other factor pairs in chromosome I and with each other. The percentage recombination was calculated by the product method.

Of the five different crosses involving *Vv* and *Ee*, two were studied in Colorado, one in Minnesota, and two in Idaho. The recombination percentages were similar in these five crosses, the average being 26.8 ± 0.6.

The factor pair *Lk lk* leads to a 1:2:1 ratio in F_2. In these studies the awned and partially awned phenotypes were combined in the F_2 data to give ratios approaching three awned and one awnless. From the cross *VV lk lk* × *vv Lk Lk* were obtained 1,996 two-rowed, awned (*V Lk*), 933 two-rowed awnless (*V lk*), and 1,045 six-rowed, fully awned (*v lk*) plants. No six-rowed awnless plants were obtained.

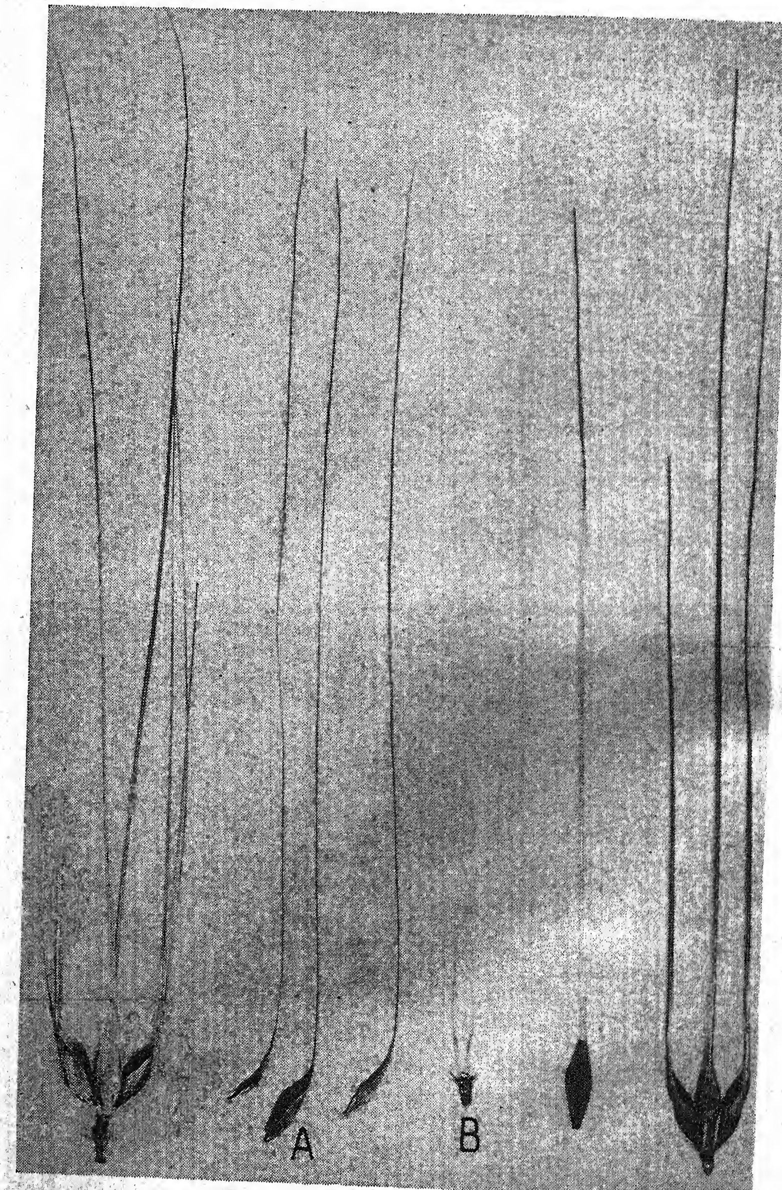


FIG. 2.—A, long-awned outer glume; B, normal glume.

Nine of the 14 crosses tested in F_2 were tested further by growing F_3 progenies of individual F_2 plants. The results are given in Table 3.

The recombination percentages in Table 3 were obtained by combining the formulae for F_3 progenies of doubly and singly dominant

TABLE 1.—*Genetic constitution of varieties used in crosses to determine linkage relations.*

Variety	Symbols of characters
Triple-bearded Mariout (C.I. 2523)..........	FF, vv, ee, Lk Lk
Gymnospermum (C.I. 2232)................	FF, VV, EE, Lk Lk
Nigrilaxum..............................	FF, VV, EE, Lk Lk
Englawnless (C.I. 2505)..................	FF, VV, EE, lk lk
Nigrinudum..............................	FF, VV, EE, Lk Lk
Minnesota 84–7..........................	ff, VV, EE, Lk Lk
Minnesota 84–7–6........................	ff, vv, EE, Lk Lk
Minnesota 72–8..........................	FF, vv, EE, Lk Lk, Yy
Trebi IV................................	FF, vv, EE, Lk Lk, Or or

TABLE 2.—*Linkage of factors in chromosome I, calculated from F_2 data.*

	Symbols		Number of plants				Total	Percentage recombination
	Xx	Yy	XY	Xy	xY	xy		
Triple-bearded Mariout ×								
Gymnospermumum......	Vv	Ee	542	90	87	122	841	23.9± 1.7
Nigrilaxum.............	Vv	Ee	1,221	246	219	243	1,929	28.2± 1.2
Nigrinudum............	Vv	Ee	290	52	52	53	447	27.9± 2.6
Englawnless............	Vv	Ee	1,396	246	292	276	2,210	28.5± 1.2
Minnesota 84–7.........	Vv	Ee	909	163	136	207	1,415	23.8± 1.3
Total.....................	Vv	Ee	4,358	797	786	901	6,842	26.8± 0.6
Minnesota 84–7............	Ff	Ee	766	337	305	6	1,414	14.5± 2.6
Trebi IV..................	Oror	Ee	658	309	287		1,254	20.3±11.2
Minnesota 84–7............	Vv	Ff	753	292	351	19	1,415	24.5± 2.5
Englawnless × Minn. 84–7–6	Vv	Ff	1,064	223	259	218	1,764	31.8± 1.4
Englawnless ×								
Minnesota 84–7–6........	Vv	Lklk	849	438	477	0	1,764	0
Triple-bearded Mariout...	Vv	Lklk	1,147	495	568	0	2,210	0
Total.....................	Vv	Lklk	1,996	933	1,045	0	3,974	0
Minnesota 84–7–6..........	Ff	Lklk	922	401	404	37	1,764	29.1± 2.2
Minnesota 72–8............	Yy	Lklk	599	291	307		1,197	13.8±17.6

F_2 plants, using the maximum likelihood formulae given by Immer (6). Under this procedure, information on linkage from F_3 data is independent of the F_2 and both sources of information can be combined to give a recombination percentage which best satisfies all data.

The recombination percentage of *Vv* and *Ff* from both F_2 and F_3 in the repulsion cross Triple-bearded Mariout × Minnesota 84–7 was 26.1 ± 1.2. In the coupling cross Englawnless × Minnesota 84–7–6, the percentage recombination was 30.4 ± 1.1. The weighted average of the percentage recombinations from both repulsion and coupling crosses will be given by weighing each recombination by the amount of information concerning the cross. The amount of information is the reciprocal of the variance. For the repulsion cross

it will be $\frac{1}{(.012)^2} = 6{,}944$, and for the coupling cross $\frac{1}{(.011)^2} = 8{,}264$.

The weighted mean recombination percentage will be

$$\frac{(26.1 \times 6{,}944) + (30.4 \times 8{,}264)}{6{,}944 + 8{,}264} = 28.4.$$

The standard error is obtained from the square root of the reciprocal of the total amount of information, i.e., $\sqrt{\frac{1}{6944 + 8264}} = .008$ or 0.8%.

Below are given the recombination percentages found from a combination of data in Tables 2 and 3:

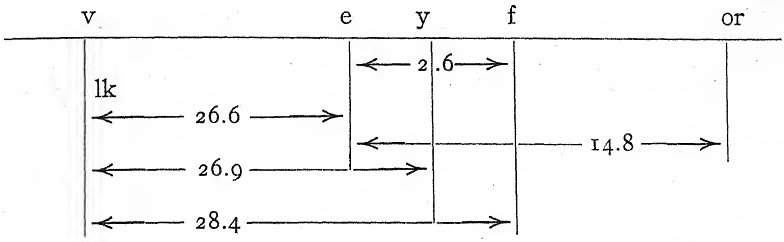
$v-e = 26.6 \pm 0.6$ $\qquad$ $v-lk = 0$
$f-e = 2.6 \pm 0.4$ $\qquad$ $f-lk = 29.9 \pm 1.2$
$or-e = 14.8 \pm 0.9$
$v-f = 28.4 \pm 0.8$ $\qquad$ $y-lk = 26.9 \pm 1.4$

TABLE 3.—*Linkage of factors in chromosome I, calculated from F_3 data.*

Cross	Symbols		Number of F_3 progenies								Percentage recombination
	Xx	Yy	XXYY	XXYy	XxYY	XxYy	XXyy	Xxyy	xxYY	xxYy	
Triple-bearded Mariout ×											
Nigrinudum	Vv	Ee	52	36	46	156	12	40	8	40	27.1±2.6
Minnesota 84-7	Vv	Ee	117	80	95	283	10	82	11	94	25.0±1.7
Minnesota 84-7	Ff	Ee	0	10	13	453	206	13	164	8	2.6±0.4
Trebi IV	Oror	Ee	6	75	88	483	222	77	—	—	14.7±0.9
Minnesota 84-7	Vv	Ff	13	102	85	278	109	81	121	93	26.9±1.4
Englawnless ×											
Minnesota 84-7-6	Vv	Ff	139	109	105	316	19	113	30	115	28.5±1.7
Minnesota 84-7-6	Vv	Lklk	0	0	0	534	267	0	265	0	0
Minnesota 84-7-6	Ff	Lklk	30	105	115	316	139	109	120	113	30.4±1.4
Minnesota 72-8	Yy	Lklk	24	123	117	336	177	114	—	—	27.4±1.4

In the case of linkage between *Ff* and *Ee*, the F_3 data alone are used above. In F_2 the ratio of phenotypes indicated $14.5 \pm 2.6\%$ recombination. In F_3 the ratio of genotypes within F_2 phenotypes is utilized. This resulted in $2.6 \pm 0.4\%$ recombination. The F_3 data are consistent in that the recombination percentages within the *FE*, *Fe*, and *fE* phenotypes were 2.4, 2.8, and 3.0%, respectively. Presumably, differential mortality in F_2 resulted in an abnormally high recombination percentage.

A chromosome map of the order of the six genes whose interrelations have been studied in this paper is as follows:



The distance between v and f was set at 28.4 since the data from the crosses involving *v–f* were more extensive than for *lk–f* and there was no crossing over between *Vv* and *Lk lk*. For similar reasons, the distance between *v–e* was set at 26.6 since the data are far more extensive than for *lk–e*. Robertson and Coleman (9) located the factors *v–y–f–or* in chromosome I and in that order. The present order is in agreement but the distances differ slightly.

The factor pair *Ee* was found to be independent of *Nn*, *Bb*, *Kk*, *Ss*, and $A_n\ a_n$, markers for chromosomes II to VI, respectively. The factor pair *Lk lk* was independent of *Bb*, $A_t\ a_t$, *Nn*, $A_{c2}\ a_{c2}$, *Kk*, *Ss*, $A_n\ a_n$, $X_c\ x_c$, $F_c\ f_c$, and $Y_c\ y_c$, which provided markers in chromosomes II, II, III, III, IV, V, VI, VI, VII, and VII, respectively.

DISCUSSION

The factor pair *Lk lk* was found to be completely linked with *Vv*. Leonard (7) found a similar factor pair *Lr lr* for normal vs. reduced lateral floret appendages to be completely linked with *Vv*. Englawnless (lk lk) is characterized by the absence of appendages on the central florets of this two-rowed variety. The variety Nudihaxtoni, used by Leonard (7), is a six-rowed variety without lateral floret appendages. Since both *Lk lk* and *Lr lr* appear to be completely linked with *Vv* and since both affect the reduction of floret appendages, one of the central florets of a two-rowed variety and the other the lateral florets only of a six-rowed variety, it is possible that the two factors for awn reduction are allelic.

SUMMARY

The linkage relations of the factor pairs *Ee* for normal vs. long outer glume and *Lk lk* for awnless vs. fully awned lemma were studied in relation to four other factors in chromosome I.

The factor pairs *Lk lk* and *Vv* were completely linked.

The gene order in chromosome I was found to be (*v*, *lk*)–*e*–*y*–*f*–*or*.

LITERATURE CITED

1. Bose, R. D., Aziz, M. A., and Bhatnagar, M. P. Studies in Indian barleys: IV. The inheritance of some anatomical characters responsible for lodging and of some ear-head characters in an interspecific cross between two Pusa barleys. Indian Jour. Agr. Sci., 7:48–88. 1937.
2. Collins, G. N. Measurement of linkage intensities. Jour. Agr. Res., 27:881–891. 1924.

3. ENGLEDOW, F. L. Inheritance in barley: II. The awn and lateral floret. Jour. Agr. Sci., 11:159–196. 1921.
4. ————. Inheritance in barley: III. The awn and lateral floret: fluctuation: a linkage: multiple allelomorphs. Jour. Gen., 14:49–87. 1924.
5. IMMER, F. R. Formulae and tables for calculating linkage intensities. Genetics, 15:81–98. 1930.
6. ————. Calculating linkage intensities from F_3 data. Genetics, 19:119–136. 1934.
7. LEONARD, W. H. Inheritance of reduced lateral spikelet appendages in the Nudihaxtoni variety of barley. Jour. Amer. Soc. Agron., 34:211–221. 1942.
8. MYLER, JAMES L. Awn inheritance in barley. Jour. Agr. Res., 65:405–412. 1942.
9. ROBERTSON, D. W., and COLEMAN, O. H. The addition of two factor pairs for chlorophyll-deficient seedlings to the linkage groups of barley. Jour. Genetics, 39:401–410. 1940.
10. ————., WIEBE, G. A., and IMMER, F. R. A summary of linkage studies in barley. Jour. Amer. Soc. Agron., 33:47–64. 1941.

EFFECTIVENESS OF CALCIUM METAPHOSPHATE AND FUSED ROCK PHOSPHATE ON ALFALFA[1]

F. J. ALWAY AND G. H. NESOM[2]

CALCIUM metaphosphate and a fused rock phosphate[3] are products developed by the Tennessee Valley Authority. Calcium metaphosphate of fertilizer grade, or "metaphos", is made by the burning of phosphorus and passage of the combustion products into raw rock phosphate. The resultant air-cooled glassy product contains about 0.3% fluorine and its phosphorus is in PO_3 combination, with a P_2O_5 equivalence of approximately 65% (4).[4] The material can be considered as corresponding to a dehydrated and substantially defluorinated concentrated superphosphate. The other product has been identified as "fused rock phosphate", but has not been accorded "official" designation. It is a glassy material of relatively low fluorine content and a high percentage of "available" P_2O_5. It is made by the fusion of rock phosphate and the quenching of the melt (5).

The evidence from field and greenhouse comparisons of these two materials with superphosphate is conflicting. On established stands of alfalfa under irrigation the metaphosphate was found inferior to superphosphate at the Montana and Idaho experiment stations but equally effective at the New Mexico station, even on a calcareous soil (Table 1). "Fused rock phosphate" proved inferior to the metaphosphate on alfalfa at the Montana and Idaho stations but was not tried at the New Mexico station.

On crops other than alfalfa the two T.V.A. (Table 2) phosphates compared more favorably with superphosphate. In nearly all of these trials the three phosphates were mixed with the surface soil before or at the time of seeding or planting the crops. The metaphosphate was found equal, or nearly so, to the superphosphate used in seven comparisons and inferior in a single comparison. The "fused rock" was similar to the other phosphates in effectiveness at four stations, while at the two where it was found inferior the methods of application are not reported. In pot experiments carried out in cooperation between the Bureau of Chemistry and Soils of the U. S. Dept. of Agriculture and 12 experiment stations, the two T. V. A. phosphates were found equal to superphosphate, except on an Arizona calcareous sandy loam of pH 9.5.

---

[1]Contribution from the Division of Soils, University of Minnesota, St. Paul, Minn., Paper No. 2101, Scientific Journal Series, Minnesota Agricultural Experiment Station. Received for publication July 10, 1943.

[2]Soils Chemist and Assistant Soils Chemist, respectively.

[3]Dr. W. H. MacIntire has pointed out that the commonly used designation "fused rock phosphate" is erroneous in that the substantially defluorinated quenched product is virtually the alpha form of tricalcium phosphate, rather than the starting apatite. He suggests that the term "fused calcium phosphate" be used until the product is accorded official designation.

[4]Figures in parenthesis refer to "Literature Cited", p. 87.

TABLE 1.—*Comparative effectiveness of calcium metaphosphate and "fused rock phosphate" top-dressed on established stands of alfalfa under irrigation.*

Author	Year of report	Effectiveness in comparison with superphosphate	
		Calcium metaphosphate	"Fused rock phosphate"
		Montana	
Green (6).......	1938	Inferior, induced less than a fourth as much increase in yield	Inferior to the metaphosphate; caused only a negligible increase
		Idaho	
Toevs and Baker (15)	1939	On one field inferior, causing no increase; on another, two-thirds as much as superphosphates	Gave no consistent increase
		New Mexico	
Hinkle (7)......	1942	No significant difference found in 14 cuttings on a calcareous soil on which both caused 40% increase in yield	Not used

In investigations by the authors, a report of which follows, the two T. V. A. phosphates were compared with treble superphosphate on alfalfa through three crop seasons on a field of Clarion clay loam in southwestern Minnesota. During two seasons the metaphosphate was tried alone on many farms in 16 counties in the western part of the state. In these trials the effectiveness of the two T. V. A. products on alfalfa was found to be governed largely by time and manner of application. This may explain the conflict in findings previously reported.

COMPARISON OF PHOSPHATES ON JACKSON EXPERIMENTAL FIELD

Treble superphosphate,[5] calcium metaphosphate, and "fused rock phosphate" were compared on a liming experimental field of Clarion clay loam in Jackson County, southwestern Minnesota, during the crop seasons of 1939, 1940, and 1941. In 1938, well in advance of seeding the alfalfa, the phosphates were incorporated in the plowed soil at two rates, namely, 44 and 88 pounds per acre of citrate-soluble P_2O_5. In 1940 they were top-dressed at the lighter rate on the 2-year-old stand on plots not previously given either commercial fertilizer or lime (Table 3). Seven cuttings of hay were obtained from the plots fertilized in 1938 and four from those top-dressed 2 years later. Thus, the effectiveness of the phosphates can be shown under two conditions, (a) thoroughly worked into the soil in advance of seeding and (b) top-dressed on a well-established stand without subsequent tillage.

[5]This was the only form of superphosphate used in the experiments.

TABLE 2.—*Comparative effectiveness of calcium metaphosphate and "fused rock phosphate" with crops other than alfalfa in pot and field experiments*

State	Author	Year of report	Crops	Method of application of phosphates	Effectiveness in comparison with superphosphate	
					Calcium metaphosphate	"Fused rock phosphate"
			Pot Experiments			
D. C.*	Ross and Jacob (9, 14)	1937	Sudan, millet, wheat, tomatoes, sweet clover	Thoroughly mixed with soil in pots	Approximately equal on acid and neutral soils, but inferior on strongly alkaline soil (pH9.5)	Similar to that of the metaphosphate
Arizona	McGeorge (10)	1939	Sudan	Mixed with upper half of soil in pots	Nearly equal	Not used
New Mexico	Hinkle (7)	1942	Sweet clover	Mixed with upper 2 inches of soil in pots	On "an alkaline calcareous soil" it increased yield 350% compared with 440% by superphosphate	Not used
			Field Experiments			
Montana	Green (6)	1938	Oats, wheat	Not stated	Much inferior	Much inferior
Tennessee	Mooers (12)	1938	Potatoes, corn, wheat, millet, soybeans, cowpeas	Not stated	Equal	Somewhat inferior
Connecticut	Brown (3)	1938	Potatoes	In bands at side and slightly below level of seed pieces	Nearly equal	Nearly equal
Massachusetts, New Jersey, Pennsylvania	Hougland, *et al.* (8)	1942	Potatoes	In 2 bands 2 inches to side and slightly below level of seed pieces	Much alike	Much alike
Kentucky	Roberts, *et al.* (13)	1942	Wheat, corn, lespedeza rotation	In hill for corn, broadcast, and worked in before drilling wheat, none on lespedeza	Practically alike	Practically alike

*U. S. Dept. of Agr. Bur. Chem. and Soils in cooperation with agricultural experiment stations of Alabama, Arkansas, Arizona, California, Connecticut, Hawaii, Illinois, Maryland, Michigan, Ohio, Rhode Island, and West Virginia.

TABLE 3.—*Summary of plot treatments in Jackson Experimental Field.*

Treatment	Applied per acre, pounds	P_2O_5 content		Applied per acre		No. of replications
		Total %	Citrate-soluble %	Citrate-soluble, pounds	Citrate-insoluble, pounds	
Applied April 27 and 28, 1938, Seven Weeks in Advance of Seeding Alfalfa						
Treble superphosphate..	100	46.0	44.0	44	2.0	5
Treble superphosphate..	200	46.0	44.0	88	4.0	5
Calcium metaphosphate	70	67.1	62.7	44	3.1	5
Calcium metaphosphate	140	67.1	62.7	88	6.2	5
"Fused rock phosphate"	250	31.9	17.5	44	36.0	5
"Fused rock phosphate"	500	31.9	17.5	88	72.0	5
Applied May 2, 1940, on 2-year-old Alfalfa						
None................	—	0.0	0.0	0	—	20
Treble superphosphate..	100	46.0	44.0	44	2.0	3
Calcium metaphosphate	70	67.1	62.7	44	3.1	3
"Fused rock phosphate"	250	31.9	17.5	44	36.0	3

The arrangement of the plots, having been set up for a liming experiment, was different from what would have been arranged for the phosphate comparison. After a detailed examination of many fields on Clarion clay loam, which occupies over half the area of Jackson County, the field had been leased late in the summer of 1937 to inaugurate a detailed study of the effect on alfalfa of lime alone and with superphosphate, potash, trace nutrients, and manure. Early in October the field, already plowed, was staked out into 1/40-acre plots, 33 by 33 feet, with 10-foot alleys between the north-south series. From each plot, a sample of surface soil was collected for pH determination. Ground limestone was then applied to alternate plots on series 1, 2, 4, 5, 7, and 10, on 30 plots in all (Fig. 1). The whole field was then disked in an east-west direction. This precaution was taken to avoid dragging lime north to south onto the adjacent unlimed plots. After the stand was established paths of 1-foot width were hoed out around plots and kept bare.

Late in the following winter, experimental quantities of calcium metaphosphate and "fused rock phosphate" were received from the Tennessee Valley Authority. Since some plots had been left unlimed, a comparison of the phosphates was fitted into the general plan of the liming experiment, as shown in Fig. 1. At the end of April, 1938, the three phosphates were applied at two rates, namely, 44 and 88 pounds per acre of citrate-soluble P_2O_5, each treatment appearing on five plots. Until seeded to Grimm alfalfa on June 15, with inoculation, the field was disked and harrowed at intervals to control weeds. A full, uniform stand of alfalfa was secured. On May 2, 1940, each phosphate was broadcasted as a top-dressing on three previously unfertilized plots. The two T. V. A. products were those applied 2 years before, an important consideration be-

cause of the variability in the properties of the metaphosphate (9). As unlimed and unfertilized controls there were 20 plots, five in each of series 1, 4, 6, and 8. The yields of hay were determined in 1939, 1940, and 1941, three cuttings in the first year and two in each of the following years (Table 4).

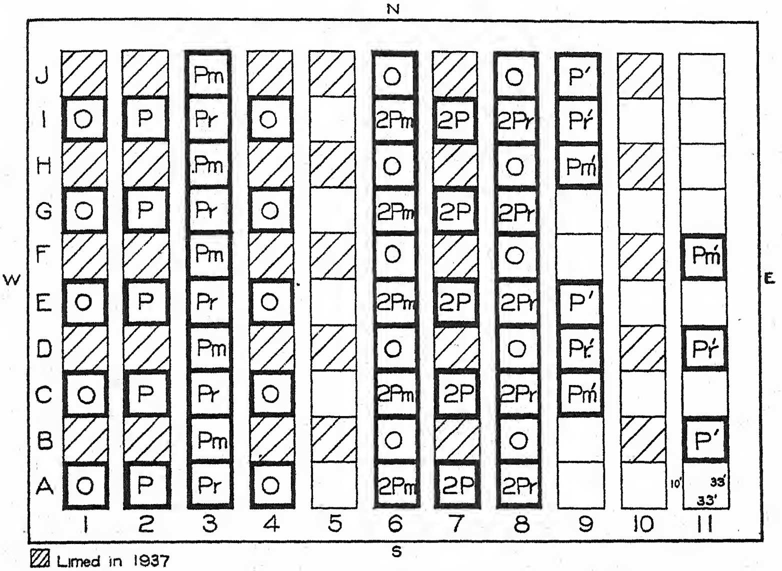


FIG. 1.—Arrangement of plots on Jackson experimental field. Plots 33 × 33 feet. with series separated by 10-foot alleys. Plots in the phosphate comparison are shown by heavier borders. P and 2P = superphosphate, Pm and 2Pm = calcium metaphosphate, Pr and 2Pr = "fused rock phosphate", all applied April, 1938, at rates of 44 and 88 pounds per acre of citrate-soluble P_2O_5. P′, Pm′, and Pr′ = the same phosphates applied April, 1940, at the lighter of the two rates.

The calcium metaphosphate induced practically the same crop increases as the superphosphate when both fertilizers were worked into the soil in advance of seeding. When applied as a spring top-dressing on the 2-year-old stand, however, the metaphosphate showed no distinct effect in the same season, although it was similar in effectiveness to the superphosphate in the following season.

Worked into the soil before seeding, the "fused rock phosphate" caused greater increases than either of the other phosphates, but it had little or no effect when applied as a top-dressing 2 years later. It should be borne in mind that, although the amount of citrate-soluble P_2O_5 introduced as fused rock was the same as in the other phosphates, the fused product carried in addition four-fifths as much P_2O_5 in a citrate-insoluble form. It therefore furnished 18 times as much of the insoluble form as the superphosphate and about 12 times as much as the metaphosphate. Evidently much of this citrate-insoluble P_2O_5 proved available on the soil of this field, which was only slightly acid.

TABLE 4.—*Effect of kind of phosphate and rate and method of application on yield of alfalfa expressed as tons per acre of air-dry hay.**

Series of plots	Kind of phosphate	No. of plots averaged	Yields, tons per acre			Increase in yield, tons per acre				
			1939	1940	1941	1939	1940	1941	1939–41	1940–41
Application on Plowed Ground of 44 Pounds Per Acre of Citrate-soluble P_2O_5, April 29, 1938										
1	None	5	2.38	1.58	1.39	—	—	—	—	—
2	Treble superphosphate	5	2.64	1.98	1.59	0.29	0.37	0.19	0.85	0.56
3	Calcium metaphosphate	5	2.64	1.99	1.47	0.29	0.38	0.07	0.74	0.45
3	"Fused rock phosphate"	5	2.92	2.27	1.70	0.57	0.66	0.30	1.53	0.96
4	None	5	2.33	1.63	1.40	—	—	—	—	—
1 and 4 av.	None	10	2.35	1.61	1.40	—	—	—	—	—
Application on Plowed Ground of 88 Pounds Per Acre of Citrate-soluble P_2O_5, April 29, 1938										
6	None	5	2.61	1.85	1.47	—	—	—	—	—
7	Treble superphosphate	5	3.26	2.59	1.99	0.72	0.71	0.55	1.98	1.26
6	Calcium metaphosphate	5	3.24	2.56	1.85	0.70	0.68	0.41	1.99	1.09
8	"Fused rock phosphate"	5	3.44	2.71	2.23	0.90	0.83	0.79	2.52	1.62
8	None	5	2.47	1.92	1.41	—	—	—	—	—
6 and 8 av.	None	10	2.54	1.88	1.44	—	—	—	—	—
Application as a Top Dressing of 44 Pounds Per Acre of Citrate-soluble P_2O_5, May 2, 1940										
8	None	5	—	1.92	1.41	—	—	—	—	—
9 and 11	Treble superphosphate	3	—	2.47	2.06	—	0.55	0.65	—	1.20
9 and 11	Calcium metaphosphate	3	—	1.87	1.99	—	0.00	0.58	—	0.58
9 and 11	"Fused rock phosphate"	3	—	1.85	1.60	—	0.00	0.19	—	0.19

*Field seeded June 16, 1938.

CALCIUM METAPHOSPHATE IN T.V.A. DEMONSTRATION PROJECT

Under a 5-year contract between the Tennessee Valley Authority and the Division of Agricultural Extension of the University of Minnesota, 503 tons of 62% calcium metaphosphate was furnished in the spring of 1940 to 205 farmers in 16 counties in western Minnesota, the farmers paying freight only. This tonnage was applied on 10,357 acres, distributed among 877 fields. Of these fields, 203 had established stands of alfalfa. On 160 fields, alfalfa was sown the same spring with a companion crop of small grains. Of the 514 other fields, 210 were devoted to hay (clovers) and 254 to pastures. To test the value of the fertilizer, at least a fifth of every field was left untreated, usually one side of the field, although some of the farmers left two strips unfertilized. Nearly all the phosphate was applied as a top-dressing to the newly seeded land during the last week in April or the month of May. In the case of the legumes with nurse crop of small grains, the intention had been to have the phosphate worked into the soil in advance of seeding. However, because of the failure of either the fertilizer or the fertilizer spreaders to reach the cooperators in time, top-dressing shortly after seeding was resorted to. The rate of application of the metaphosphate was 100 to 130 pounds per acre, except on a few fields where the rate was only half as heavy.

The fertilization and determination of yields were under the supervision of the same person that harvested the alfalfa on the Jackson experimental field. At the meetings in the different counties, when the cooperating farmers were selected, it was reported that calcium metaphosphate had been found the equal of superphosphate on the Jackson experimental field. Many field trials by the Agricultural Experiment Station during the preceding 20 years had well established the generally beneficial effect of superphosphates when used as a top-dressing on alfalfa in the western counties. The results in 1940 were extremely disappointing, but in the following season the cooperators' expectations of benefit from the new fertilizer were more nearly realized.

The yields on these fields were determined by the square yard method (1). Shortly before mowing a field, samples of alfalfa were collected from representative areas of the fertilized and unfertilized parts, each sample being the entire growth on six well-separated 1-yard squares. These samples were allowed to become thoroughly air-dry before being weighed. Since the field force was not adequate to admit the sampling of each cutting on every field without unduly delaying the hay-making, only 153 fields were sampled in 1940 and 191 in 1941. There were 265 pairs of samples in 1940 and 330 in 1941, thus providing 595 comparisons. On some fields the yield was determined by only one cutting, but on many fields there were two cuttings. On a few fields in the southwestern counties, however, three cuttings were sampled, as illustrated in Table 5.

The results of the two seasons are summarized in Table 6, the data being averaged for three groups of counties as follows: (a) The five in the southwestern part of the state, where it is common practice

TABLE 5.—*Increase in yield of alfalfa hay in Jackson County, Minn., from application of calcium metaphosphate in spring of 1940, illustrating method of computing average increase.*

Cooperators	Field	1940			1941		
		First cutting, ton	Second cutting, ton	Third cutting, ton	First cutting, ton	Second cutting, ton	Third cutting, ton
H. B.	G	—	—	—	—	0.12	0.16
F. B.	I	0.20	—	0.00	—	—	—
R. B.	A	−0.04	0.04	0.04	—	0.20	0.37
B. G.	B	0.12	−0.08	0.00	—	—	—
A. G.	E	—	—	—	—	—	0.12
A. H.	D	—	—	—	0.94	0.55	0.53
N. H. H.	F	—	—	—	—	0.65	0.36
L. H. H.	L	—	—	—	0.21	0.09	0.16
C. E. L.	D	—	0.09	0.04	—	0.16	0.08
P. M.	K	—	0.04	0.00	—	0.12	—
F. R.	M	0.20	—	0.00	—	0.20	0.00
S. R.	F	—	—	—	0.18	0.32	0.16
E. V. O.	H	−0.04	0.04	0.04	0.41	—	0.24
Average.		0.11	0.01	0.01	0.43	0.27	0.22
Total for season, ton			0.13			0.92	

to mow alfalfa three times in a season; (b) the eight which occupy the northwestern corner of the state; and three separated counties between the other groups (Fig. 2). The average yields for the two seasons, 1940 and 1941, were similar, for the southwestern group 2.43 and 2.48 tons and for the northwestern 2.11 and 2.09 tons. In 1940, the increase from fertilization in general was small, only 0.17 ton per acre for the southwestern group, but in the following season

TABLE 6.—*Effect of calcium metaphosphate on alfalfa in T.V.A. test demonstration project in Minnesota.*

	5 southwestern counties*		3 west-central counties†		8 northwestern counties‡	
	1940	1941	1940	1941	1940	1941
Fields sampled, number.	79	79	23	26	51	86
Pairs of samples collected, number. .	171	157	28	41	66	132
Average yield in season without phosphate, tons.	2.43	2.48	2.24	1.68	2.11	2.09
Average increase with phosphate:						
In first cutting, ton.	0.09	0.17	0.11	0.24	0.10	0.33
In second cutting, ton.	0.03	0.21	0.13	0.21	0.21	0.29
In third cutting, ton.	0.05	0.25	—	—	—	—
In season, ton.	0.17	0.63	0.24	0.45	0.31	0.62
In season, %.	7	25	11	27	15	30

*Jackson, Martin, Nobles, Watonwan, and Brown counties.
†Yellow Medicine, Stevens, and Kandiyohi counties.
‡Roseau, Kittson, Marshall, Polk, Pennington, Red Lake, Mahnomen, and Norman counties.

the increase was more than three times as much. In the northwestern group the increase averaged 0.31 ton in 1940 and 0.62 ton in 1941, with more fields showing an appreciable benefit from the fertilizer.

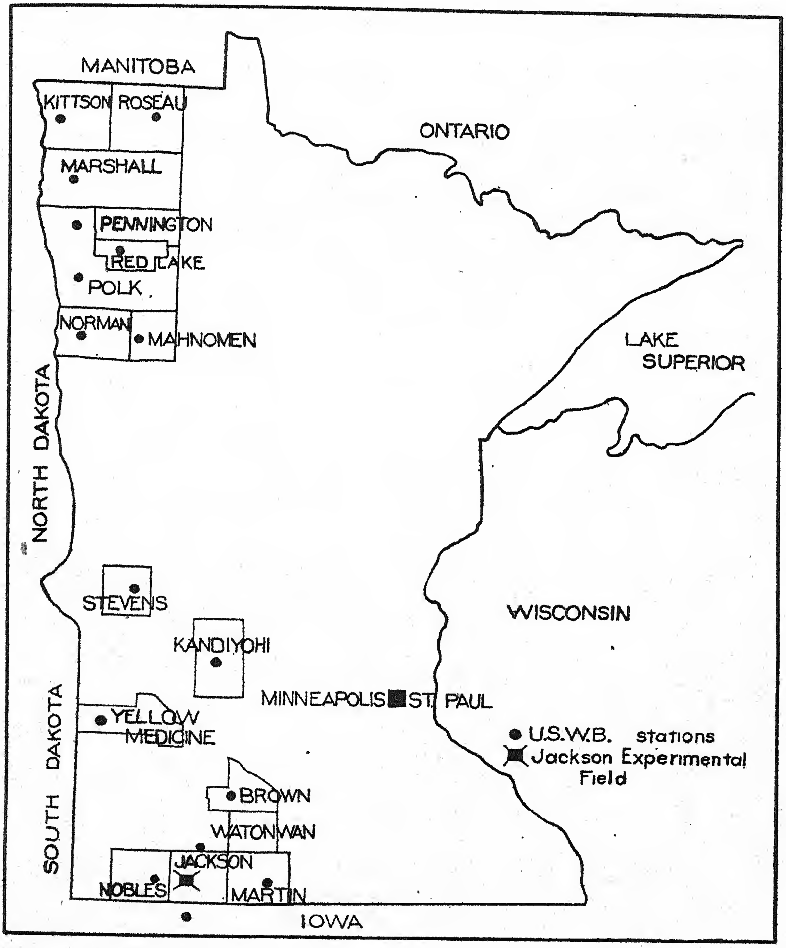


FIG. 2.—Map of Minnesota, showing counties in the metaphosphate-test-demonstration project.

On only 13 fields was the yield determined for all cuttings in both seasons, three cuttings in the southwestern and two in the northwestern counties (Table 7). The results, are concordent with those that included the 140 or more additional fields on which not all cuttings were sampled, as summarized in Table 6. It appears that in 1941 those of the fields in the southwestern counties that showed the most marked benefit from the phosphate were given preference in sampling.

TABLE 7.—*Effect of calcium metaphosphate top-dressed in spring of 1940 on all fields in T.V.A. project in which every cutting was sampled.*

Applied on established stand of alfalfa						Applied on alfalfa newly sown with small grain, 1941			
County	Cooperator	Yield without phosphate, tons		Increase with phosphate, tons		County	Cooperator	Yield without phosphate, tons	Increase with phosphate, tons
		1940	1941	1940	1941				
Southwestern Counties									
Brown	J. A. E.	2.30	2.86	0.01	1.74	Jackson	A. H.	1.83	2.02
Brown	O. F.	2.02	2.80	0.00	0.35	Jackson	L. H. H.	1.72	0.46
Martin	T. N.	3.15	2.14	0.39	1.93	Martin	F. L. B.	1.45	1.94
Martin	W. J. S.	2.81	2.74	0.42	1.05	Martin	K. O.	1.77	1.93
Nobles	D. M.	3.02	2.99	−0.16	0.52	Nobles	W. H. G.	2.06	0.69
Nobles	J. L. M.	2.37	2.86	0.24	0.20	Nobles	C. H.	2.54	0.29
Watonwan	W. L.	1.56	1.77	0.29	1.61	Watonwan	P. J. Z.	2.17	2.15
Average		2.46	2.59	0.17	1.06			1.93	1.27
Northwestern Counties									
Red Lake	B. B.	2.74	2.50	0.40	0.72	Red Lake	C. W. B.	2.30	0.48
Red Lake	C. H.	2.53	1.85	−0.23	0.53	Red Lake	N. J. F.	2.86	0.28
Roseau	E. J.	4.19	1.78	0.40	0.52	Roseau	A. W. E.	1.49	0.81
Roseau	H. P.	1.94	1.86	0.24	0.80	Roseau	C. W.	1.77	0.41
Mahnomen	A. C.	1.87	1.90	0.39	0.60	Pennington	H. B.	1.74	0.44
Pennington	H. I. F.	3.30	2.46	0.20	0.48	Pennington	H. I. F.	2.46	0.48
						Pennington	A. J. J.	2.14	0.92
						Pennington	G. O.	1.49	0.97
						Kittson	A. S.	1.57	0.37
						Kittson	L. C. W.	1.49	0.45
						Marshall	B. F.	1.37	0.93
						Norman	R. A.	1.69	0.77
						Norman	C. N.	1.53	1.62
						Polk	N. B.	2.18	0.68
						Polk	K. J.	1.82	0.40
						Polk	M. S.	1.50	0.60
						Polk	P. J. S.	1.73	0.97
Average		2.76	2.06	0.23	0.61			1.83	0.70

Of the 160 fields seeded with small grains in 1940 only 24 had every cutting sampled the following season, 7 in the southwestern counties and 17 in the northwestern (Table 8). Although the increase in yield induced by phosphate on these fields was somewhat greater than on those seeded before 1940, the variation within both groups is sufficient to indicate that the top-dressing was no more effective on the newly sown fields than on those of established stands. From the T. V. A. project as a whole the conclusions to be drawn are in accord with those from the Jackson experimental field, *viz.*, that as a spring top-dressing for alfalfa, calcium metaphosphate is far less effective than superphosphate in the season of application, whereas in the following season there is no marked difference.

TABLE 8.—*Effect of top-dressing with calcium metaphosphate on established stands compared with that on newly sown alfalfa.**

Southwestern counties			Northwestern counties		
Phosphate top-dressed on old seeding		Phosphate top-dressed on new seeding, 1941	Phosphate top-dressed on old seeding		Phosphate top-dressed on new seeding, 1941
1940	1941		1940	1941	
Number of Fields Employed in Comparison					
7	7	7	6	6	17
Average Yield in Season* Without Phosphate, Tons†					
2.46	2.59	1.93	2.76	2.06	1.85
Increase in Season from Phosphate, Tons					
0.17	1.06	1.27	0.23	0.61	0.70
Percentage Increase from Phosphate					
7	37	66	10	29	38

*The phosphate was applied on all the fields in the spring of 1940.
†Three cuttings in southwestern counties but only two in northwestern counties.

ACIDITY OF THE SOIL

In seeking a cause of the lesser effectiveness of the two T. V. A. phosphates when applied as a top-dressing, it is well to consider the reaction of the soil. Ross and Jacob (14) found both metaphosphate and the fused product much inferior to superphosphate on strongly alkaline soil. We have very definite information as to the acidity of the Jackson experimental field. A composite of 20 individual samples of the surface soil was obtained from every plot in October, 1937, after the field had been staked out in plots and before applications. The pH values for the phosphate-treated and the control plots, shown in Table 9, were determined potentiometrically with a glass electrode. The lowest value is 5.7 and the highest 7.1. On three-fourths of the plots the values fall within the 6.0 to 6.7 range, on

about an eighth they are below 6.0, and on the remaining eighth from 6.8 to 7.1. (That the subsoil is very calcareous is shown (Table 10) by pH determinations in composite samples taken at the same time as the surface samples.)

TABLE 9.—*The pH values of surface soil on plots used in the phosphate comparsion on the Jackson experimental field.*

Plot	Ser. 1	Ser. 2	Ser. 3	Ser. 4	Ser. 6	Ser. 7	Ser. 8	Ser. 9	Ser. 11
J	—	—	5.7	—	6.1	—	5.9	6.0	—
I	6.1	6.0	5.7	6.1	5.7	6.0	5.7	6.0	—
H	—	—	5.8	—	6.2	—	6.0	6.0	—
G	6.4	6.4	6.0	6.1	6.0	6.1	6.0	—	—
F	—	—	6.5	—	6.0	—	6.3	—	7.1
E	7.0	7.0	6.6	6.7	6.0	6.6	6.1	6.0	—
D	—	—	6.5	—	6.5	—	6.0	6.1	6.3
C	6.8	6.9	6.7	6.5	6.5	6.7	6.3	6.4	—
B	—	—	6.6	—	6.4	—	6.2	—	7.1
A	7.0	6.7	6.8	6.7	6.6	6.6	6.6	—	—

No distinct correlation was found in a detailed comparison of pH values with yields on the five replicates of the three phosphates at both rates. Although on four-fifths of the plots the surface soil was slightly acidic, the application of 2 tons per acre of ground limestone 8 months before seeding showed no effect on the stand or on the appearance of the alfalfa at any time during the experiment and on the 30 limed plots the yield averaged practically the same as on the 30 adjacent plots which had been treated similarly except for liming. The alfalfa showed no distinct benefit from either potash or gypsum applied along with treble superphosphate, or from the less commonly added nutrients, boron, copper, manganese, magnesium, and zinc, applied in April, 1938, on inlimed plots, the first in the form of borax and the others as sulfates.

TABLE 10.—*The pH values of four sets of composite samples from near the corners of the Jackson experimental field collected at the same time as the surface samples.*

Depth, inches	Southeast corner	Southwest corner	Northeast corner	Northwest corner
1–6	6.7	7.1	6.1	5.9
7–12	6.6	7.1	6.5	5.7
13–24	7.3	7.8	7.0	5.9
25–36	8.5	8.1	7.9	7.3

The acidity of the soil was not determined for the fields employed in the T. V. A. test-demonstration project. It is safe to assume, however, that in nearly all the fields the pH values would lie within the limits found on the Jackson experimental field, since only a few in the northwestern counties were appreciably higher, i.e., between 7.5 and 8.5. Alfalfa and also sweet clover, which is even more sensitive to lime deficiency, is grown extensively in the several counties, in none of which is liming practiced. Moreover, no evidence has been advanced to indicate that liming would be of appreciable

benefit except on some the soils of coarse texture and these are of very limited extent. In 1941, the average area per farm of these two legume crops in the 16 counties varied from a maximum of 41 acres in Roseau County where they occupied 49% of the crop land to a minimum of 7 acres in Martin County where only 5% of the crop land was devoted to these two legumes. The smaller proportion of the crop land devoted to these lime-demanding legumes in the southwestern counties is due not to a less favorable soil but to a climate more favorable for corn. In 1941, Martin County had an average of 57 acres of corn per farm, whereas Roseau County had only 3 acres, chiefly for silage.

The barely neutral or slightly acidic soils, such as those of the experimental field, appear to be not at all unfavorable to either of the two T. V. A. phosphates, provided they are well incorporated with the soil. Even as a top-dressing the calcium metaphosphate compared favorably with superphosphate after a lapse of only 1 year. If the rainfall had been heavier and better timed, the benefit of the fertilizer might have appeared much earlier.

INFLUENCE OF RAINFALL ON EFFECTIVENESS OF CALCIUM METAPHOSPHATE

When well incorporated with the soil in advance of seeding, calcium metaphosphate was found as effective as superphosphate on the Jackson experimental field. When spring top-dressed on an established stand, however, the metaphosphate was much inferior to superphosphate, although in the second season the two phosphates had practically the same effect. This delayed action from a top-dressing, confirmed by the trials in the T. V. A. project, may be attributed to the slowness with which the grainy metaphosphate, or the hydrolysis product, is dissolved by the rain and carried down within reach of the plant roots. Most of the superphosphate is water-soluble, whereas MacIntire (9) has found that the calcium metaphosphate may have as little as 7.1% of its total phosphorus dissolved by 48 hours extraction with water. He found also that the amount extractable by water within a 48-hour period as well as the rate at which the metaphosphate hydrolyzed to the orthophosphate is governed by the ratio of P_2O_5 to CaO and by the nature and quantity of SiO_2 content. A liberal and well-distributed rainfall following a top-dressing might be expected to increase the early effectiveness of the metaphosphate.

Our information as to the precipitation at the Jackson experimental field is much less satisfactory than that as to the acidity of the soil. No rain gage was maintained at the field and the nearest U. S. Weather Bureau stations are at Worthington, Minn., 18 miles to the west; Windom, Minn., 20 miles to the northeast; and Lake Park, Iowa, 13 miles to the south. During the four crop seasons in which the field was operated by the Agricultural Experiment Station, the precipitation at these three stations was similar. It may be assumed, therefore, that precipitation at the experimental field was much the same as that at Worthington (Table 11). The rainfall for 1938.

the season in which the alfalfa was seeded, was very high, being nearly twice the normal in May and June. There was no further wide departure from normal until September, when exceptionally heavy rains fell, 11.2 inches at Worthington, 8.4 inches at Windom, and 10.5 inches at Lake Park. During the 5 months following the working of the phosphates into the soil, 32.0 inches fell at Worthington rather than the normal of 18.8. In 1939, the precipitation was somewhat less than normal but its distribution was unusually favorable. In 1940, following the top-dressings on May 2, the rainfall was light, with a negative departure of 1.3 inches between that date and the first cutting of hay, June 28, and of 3.0 inches between the first cutting and the second, July 26. Between the latter date and that of the first cutting in 1941, June 7, there was a negative departure of 2.4 inches, making a total of 6.7 inches below the normal since the phosphates were top-dressed. After the application of the phosphates at the end of April, 1938, and until the end of August 1941, the total precipitation was 2.1 inches in excess of normal. On the whole, the precipitation during the period of this part of the experiment may be considered normal. For the 16-month period of the top-dressing experiment, May 2, 1940, to August 31, 1941, the precipitation was 7.2 inches below normal and unfavorable in distribution; yet the metaphosphate caused an increase almost equal to that from the superphosphate in the second season.

TABLE 11.—*Precipitation at Worthington, Minn., in the years of the experiments on the Jackson experimental field.*

Month	Normal, inches	1938, inches	1939, inches	1940, inches	1941, inches
Jan.	0.6	0.7	0.4	Trace	0.6
Feb.	0.8	1.7	0.8	0.8	0.8
Mar.	1.3	1.5	0.4	2.0	1.1
Apr.	2.1	2.4	1.8	2.8	4.1
May	3.9	7.3	2.5	1.2	0.6
June	4.3	7.9	5.5	5.7	5.7
July	3.4	3.2	6.4	0.3	2.7
Aug.	3.7	2.4	4.2	2.8	2.1
Sept.	3.5	11.2	0.7	0.7	5.1
Oct.	1.7	0.3	1.3	2.8	2.9
Nov.	1.2	1.2	Trace	2.7	1.7
Dec.	0.6	0.8	0.3	0.8	0.9
Year	27.1	40.5	24.3	22.5	28.2

The preceding statements regarding the weather at the Jackson experimental field also apply to the southwestern group of five counties in the T. V. A. demonstration project. In the northwestern group there are records from nine U. S. Weather Bureau stations well distributed over the eight counties. In this area the crop season of 1940 was slightly cooler and much drier than normal, with negative departures at all nine stations for June, July, and the 4-month period of May to August. The following season was somewhat warmer than normal and considerably wetter, although July

was drier at all the stations. For the 16-month period between the top-dressing with phosphate in May, 1940, and the end of August, 1941, the average amount of precipitation at the nine stations was 1.5 inches above normal. Judging from the yields on the unfertilized parts of the fields seeded before 1940, 2.11 tons per acre in 1940 and 2.09 tons in 1941 (Table 6), the weather was about as favorable for alfalfa in the one crop season as in the other.

SUMMARY

Using alfalfa as the trial crop, calcium metaphosphate and "fused rock phosphate" were compared with superphosphate on a field of Clarion clay loam, the surface soil of which was slightly acidic but not lime-deficient. Seven weeks before seeding the alfalfa, the three phosphates were applied at two rates, namely, 44 and 88 pounds per acre of citrate-soluble P_2O_5, and worked into the soil. Two years later these phosphates were top-dressed at the lower rate on well-established alfalfa stands on plots not previously fertilized.

Applied on the plowed ground in advance of seeding, the metaphosphate increased the yield virtually as much as the superphosphate in each of the following three crop seasons. When spring top-dressed on the established stand, metaphosphate was far inferior to superphosphate in the first season, but almost equal in the second. When applied at a rate giving as much citrate-soluble and considerably more total P_2O_5, and worked in before seeding, the "fused rock phosphate" caused larger yields than the other phosphates throughout the 3 years of the experiment, but it showed little or no benefit when used as a top-dressing.

In 16 counties in western Minnesota, where lime deficiency is of rare occurrence, calcium metaphosphate was tried alone as a spring top-dressing on alfalfa, using many established fields and also many newly sown with small grains. The benefit in the first season was slight but in the second much greater.

It appears that both calcium metaphosphate and the T. V. A. product commonly designated "fused rock phosphate" will be as effective as superphosphate when well incorporated with the soil in advance or at time of seeding or planting of crops, at least on all but calcareous soils.

It is suggested that conflicting evidence previously presented as to the effectiveness of the two phosphatic materials may be attributed to the differences in manner and time of application employed by the various investigators.

LITERATURE CITED

1. ARNY, A. C., and STEINMETZ, F. H. Field technic in determining yields of experimental plots by the square yard method. Jour. Amer. Soc. Agron., 11:81–106. 1919.
2. BECK, M. W., ELWELL, J. A., HALL, J. S., and BODMAN, G. B. Soil Survey of Jackson County, Minnesota. U.S.D.A., Bur. Chem. and Soils, Field Operations (1923). 1928.
3. BROWN, B. A. Fertilizers for potatoes. Conn. (Storrs) Agr. Exp. Sta. Bul. 223. 1938.

4. CURTIS, H. A., COPSON, R. L., and ABRAMS, A. J. Metaphosphate investigation aims at cheaper fertilizers. Chem. and Met. Eng., 44:140–142. 1937.
5. ELMORE, K. L., HUFFMAN, E. O., and WOLF, W. W. Defluorination of phosphate rock in the molten state. Ind. and Eng. Chem., 34:40–48. 1942.
6. GREEN, J. R. Phosphate investigations on irrigated crops 1937. Mont. Agr. Exp. Sta. Bul. 356. 1938.
7. HINKLE, D. A. Efficiency of various phosphate fertilizers on calcareous soil for alfalfa and sweet clover. Jour. Amer. Soc. Agron., 34:913–918. 1942.
8. HOUGLAND, G. V. C., CLARK, K. G., HAWKINS, A., and CAMPBELL, J. C. Nutrient value of some new phosphatic materials used on potatoes. Amer. Fert., 97, No. 7:5–8; 24–25. 1942.
9. JACOB, K. D., and ROSS, W. H. Nutrient value of the phosphorus in defluorinated phosphate, calcium metaphosphate and other phosphatic materials as determined by the growth of plants in pot experiments. Jour. Agr. Res., 61:539–560. 1940.
10. MCGEORGE, W. T. Factors influencing the availability of native soil phosphate and phosphate fertilizers in Arizona soils. Ariz. Agr. Exp. Sta. Tech. Bul. 82. 1939.
11. MACINTIRE, W. H., HARDIN, L. J., and OLDHAM, F. D. Calcium metaphosphate fertilizers: Chemical composition and properties. Ind. and Eng. Chem., 29:224–231. 1937.
12. MOOERS, C. A. An evaluation of the Neubauer and the *Cunninghamella* and *Aspergillus niger* methods for the determination of the fertilizer needs of a soil. Soil Sci., 46:211–227. 1938.
13. ROBERTS, G., FREEMAN, J. F., and MILLER, H. Field tests of the relative effectiveness of different phosphate fertilizers. Ky. Agr. Exp. Sta. Bul. 420. 1942.
14. ROSS, W. H., and JACOB, K. D. Availability of calcined phosphate and other new phosphate materials as determined by chemical and vegetative tests. Jour. Assoc. Agr. Chem., 20:231–249. 1937.
15. TOEVS, J. L., and BAKER, G. O. Progress report of phosphate and other fertilizer investigations. Idaho Agr. Exp. Sta. Bul. 230. 1939.

NOTE

MUTATIONS FOR WAXY AND SUGARY ENDOSPERM IN INBRED LINES OF DENT CORN

IN THE breeding program of the Bear Hybrids Corn Company, there have been three waxy mutations and one sweet mutation in dent corn since 1936. All of these mutations occurred in inbred lines. Apparently they are the same type of mutation as reported by Mangelsdorf,[1] but they can definitely be identified as mutations because of their occurrence in inbred lines.

The first waxy mutation probably occurred in 1936, although it was not observed until 1938. When it was first noticed in 1938, all kernels of one ear of the 1938 ear-row were waxy, while other ears in the same row bred true for dent or segregated in the ratio of 3 dent: 1 waxy. The line in which this mutation occurred was a third year self from a cross between open-pollinated Champion White Pearl and a yellow inbred which had been selfed for 8 years.

The second mutation was observed in 1939 in an ear of a yellow line which had been inbred ear-to-row for 7 years. This inbred line, Bear 13, is one developed by the writer's father, A. Linn Bear, from

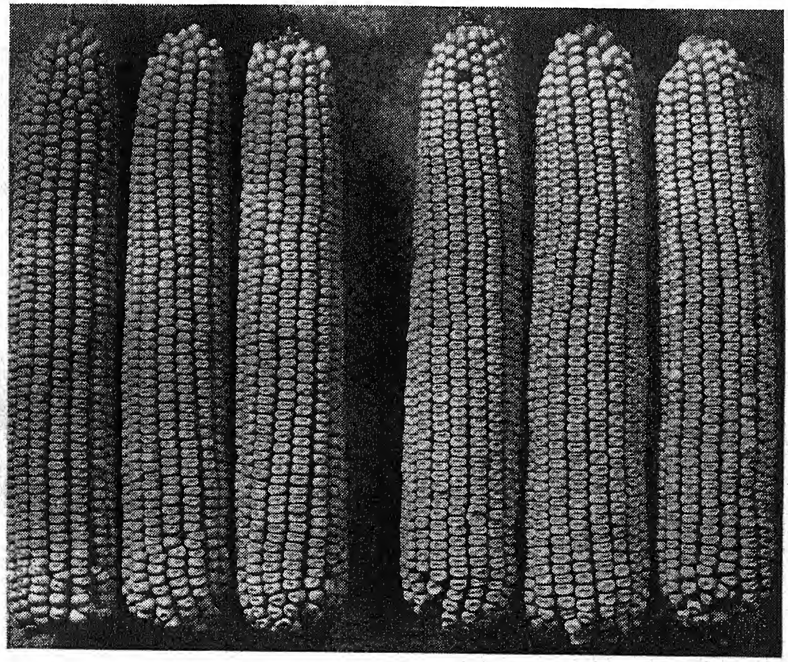


FIG. 1.—*Left*, Waxy 38–11 × Bear 13; *right*, Dent 38–11 × Bear 13.

---

[1]MANGELSDORF, P. C. Waxy endosperm in New England maize. Science, 60:222. 1924.

Krug open-pollinated corn. In 1940, the dent kernels from this ear were planted in one row and the waxy kernels were planted in an adjacent row. During the summer the plants in these rows were closely checked, and at no time was there any difference in the vigor, color, silking date, or other plant characteristics. Both rows were identical with other ear rows of the same inbred in which the mutation had not occurred. This mutation was also a simple recessive to dent.

The third mutation was observed in 1940 in inbred Indiana 38–11. This was also a simple recessive to dent corn. Our 38–11 came from the Illinois Agricultural Experiment Station in 1937, from that year it has been selfed in our nurseries. As in the case of Bear 13, the two types of kernels on the segregating 38–11 ear were planted side by side and no plant differences could be noted. Here again was a

TABLE 1.—*Segregation of dent and waxy endosperm on 71 ears of 38–11.*

Total kernels	Dent kernels	Actual waxy kernels	Expected waxy kernels	Total kernels	Dent kernels	Actual waxy kernels	Expected waxy kernels
546	426	120	137	325	241	84	81
513	376	137	128	321	244	77	80
506	388	118	126	314	237	77	79
504	392	112	126	313	234	79	78
498	394	104	124	313	240	73	78
494	391	103	123	311	230	81	78
482	355	127	120	309	222	87	77
477	361	116	119	303	230	73	76
476	376	100	119	292	231	61	73
473	349	124	118	290	235	55	73
469	351	118	117	287	220	67	72
466	348	118	117	284	214	70	71
463	334	129	116	276	210	66	69
456	330	126	114	262	199	63	66
447	330	117	112	258	194	64	65
445	351	94	111	256	193	63	64
443	339	104	111	253	192	61	63
441	336	105	110	252	197	55	63
420	327	93	105	248	190	58	62
419	342	77	105	244	188	56	61
411	305	106	103	242	190	52	61
411	314	97	103	221	169	52	55
406	301	105	102	206	144	62	52
401	313	88	100	203	161	42	51
399	307	92	100	201	154	47	50
398	308	90	100	192	148	44	48
391	295	96	98	175	116	59	44
391	308	83	98	171	123	48	43
378	289	89	95	160	113	47	40
361	280	81	90	148	117	31	37
357	271	86	89	148	117	31	37
355	268	87	89	145	112	33	36
353	271	82	88	136	110	26	34
351	281	70	88	70	55	15	18
336	254	82	84	48	37	11	12
333	256	77	83				
Totals				23,647	18,024	5,623	5,915

mutation in an inbred line apparently involving only the wx gene. In 1942, kernels borne on 71 segregating ears were classified and counted; 23.77% of the kernels were waxy and 76.23% were dent (Table 1 and Fig. 1). This deviation from the expected 3:1 ratio in a dent: waxy segregation is about of the same order as that obtained by Kisselbach and Petersen.[2]

These are true mutations for two reasons. First, there was no waxy in our nursery at the time these mutations occurred; and second, there has been no noticeable difference in the plant characters of the waxy and nonwaxy plants.

All of these waxy inbreds were identified by the iodine test.

When waxy 38–11 was crossed with waxy Bear 13, the F_1 was waxy, demonstrating that both parental lines carried the same waxy gene. In 1943, the waxy single cross was checked for yield against the single cross of the same two dent inbreds. One year's data indicate no change in yield factors—both single crosses outyielding U. S. 13, which was used as a check in these comparisons.

In 1942, one ear of the 38–11 segregating for dent and waxy was found to have not only dent and waxy kernels but also sweet kernels. This was a very inferior ear, so no accurate count could be made to determine the segregating ratio. All three types of kernels from this ear were planted in 1943, with the result that the plant types of all three were typical of inbred 38–11. The sweet grains bred true for sweet. Of the eight plants that came from waxy kernels, three bred true for waxy and five segregated in the ratio of 3 waxy: 1 sweet. Of the 21 plants that came from dent kernels, 6 bred true for dent; 6 segregated in the ratio of 3 dent: 1 sweet; and 9 segregated, indicating a ratio of 9 dent: 3 waxy: 4 sweet. None of the plants segregated for dent and waxy alone.

The fact that the waxy mutations have occurred will account in part for the appearance of waxy corn that has been reported from several different countries in the world. Certainly when it has occurred at least three times in approximately 100,000 selfs made by the Bear Hybrids Corn Company, it probably has occurred occasionally in other breeding programs.—ROBERT P. BEAR, *Bear Hybrids Corn Company, Decatur, Ill.*

[2]KISSELBACH, T. A., and PETERSEN, N. F. The segregation of carbohydrates in crosses between waxy and starchy types of maize. Genetics, 11:407–422. 1926.

BOOK REVIEW

AGRICULTURAL PRODUCTION IN CONTINENTAL EUROPE DURING THE 1914–18 WAR AND THE RECONSTRUCTION PERIOD

League of Nations Publication. New York: Columbia Univ. Press, International Documents Service. 122 pages, with tables and map diagrams. 1943. $2.25, cloth; $1.75, paper.

THIS contribution from the League of Nations contains much information of interest and value to all who are thinking of the restoration of Europe's agricultural production at the close of the war. It is pointed out that it required seven years for the continent of Europe to regain its pre-war food production level after World War I. The world food situation at the close of the present war will undoubtedly be much more complex, although the means to cope with the problem will be better organized.

Data are presented on production, trade, and consumption of major foodstuffs in the regions most affected by the first World War, for the war and early postwar periods. In the light of these data, the reasons for the drastic decline in agricultural production and its slow recovery are analyzed. The work is one of a series of studies which the League of Nations is devoting to a consideration of the lessons to be learned from the past which may prove of value as policies for the postwar world are formulated. It surveys the changes of agricultural production by regions, countries, and provincial districts, and examines the various factors responsible for these changes.

It also presents a broad summary of the trends of production and consumption during the whole inter-war period. There are comparisons of the production and trade of Europe with those of the British Isles and Russia, treated as regions apart from continental Europe, and with North America and a group of cereal-exporting countries of the Southern Hemisphere, the two latter regions being considered as sources from which Europe could cover her import requirements. The basic data are graphically presented by means of detailed tables and map diagrams.

In conclusion, a comparison is made of the situation at the end of the fourth year of the present war with that at the same point in the previous war which indicates that the need for initial relief from overseas and for assistance in reconstruction will be greater and more urgent than before.—J. D. LUCKETT.

AGRONOMIC AFFAIRS

STANDING COMMITTEES OF THE AMERICAN SOCIETY OF AGRONOMY FOR 1944

FERTILIZERS

R. W. Cummings, *General Chairman*

SUBCOMMITTEE ON FERTILIZER APPLICATION

J. A. Chucka, *Chairman*
F. E. Bear
F. E. Boyd
E. R. Collins
H. J. Harper
S. B. Haskell
M. S. Hazen
W. T. McGeorge
J. E. McMurtrey
C. E. Millar
R. M. Salter
G. D. Scarseth
H. R. Smalley
S. C. Vandecaveye
C. W. Whittaker
R. E. Yoder

SUBCOMMITTEE ON DIAGNOSIS OF PLANT NUTRIENT STATUS

G. D. Scarseth, *Chairman*
R. H. Bray
R. L. Carolus
H. D. Chapman
J. A. Chucka
O. W. Davidson
J. B. Hester
G. N. Hoffer
M. F. Morgan
Michael Peech
J. R. Piland
C. B. Sayre
G. W. Volk

SUBCOMMITTEE ON FERTILIZER RATIOS

C. E. Millar, *Chairman*
R. V. Allison
R. P. Bartholomew
F. C. Bauer
Richard Bradfield
J. A. Chucka
R. W. Cummings
T. B. Hutcheson
M. H. Lockwood
D. D. Long
H. B. Mann
R. P. Thomas
S. C. Vandecaveye
N. J. Volk
R. E. Yoder
H. H. Zimmerley

SUBCOMMITTEE ON NITROGEN UTILIZATION

F. E. Bear, *Chairman*
O. S. Aamodt
R. W. Cummings
W. H. Pierre
S. C. Vandecaveye
N. J. Volk

ADVISORY COMMITTEE TO WAR FOOD ADMINISTRATION

R. W. Cummings, *Chairman*
Richard Bradfield
N. J. Volk
R. E. Yoder

SOIL TILTH

B. T. Shaw, *General Chairman*

FOR AMERICAN SOCIETY OF AGRONOMY

B. T. Shaw, *Chairman*
L. B. Olmstead
L. D. Baver
E. N. Fergus

FOR AMERICAN SOCIETY OF AGRICULTURAL ENGINEERS

L. F. Reed, *Chairman*
M. L. Nichols
B. A. Jennings
A. P. Yerkes

CROPS SECTION COMMITTEES FOR 1944

VARIETAL STANDARDIZATION AND REGISTRATION

M. A. McCall, *Chairman*
A. C. Arny
H. B. Brown
J. Allen Clark
F. N. Briggs
L. F. Graber
H. K. Hayes
E. A. Hollowell
R. E. Karper
W. J. Morse
T. R. Stanton
T. M. Stevenson
G. H. Stringfield

NOMENCLATURE OF GENETIC FACTORS IN WHEAT

E. R. Ausemus, *Chairman*
F. N. Briggs
J. P. Harrington
L. P. Reitz
W. W. Worzella

METHODS OF SEED PRODUCTION AND UTILIZATION OF IMPROVED STRAINS OF FORAGE CROPS

R. D. Lewis, *Chairman*
O. S. Aamodt
H. R. Albrecht
A. L. Clapp
O. S. Fisher
E. F. Frolik
L. F. Graber
F. V. Grau
E. A. Hollowell
R. D. Mercer
H. C. Rather
H. A. Schoth
H. M. Tysdal
R. G. Wiggans
J. C. Hackleman

CROP TERMINOLOGY

C. J. Willard, *Chairman*
K. S. Quisenberry
C. P. Wilsie

NEWS ITEMS

In addition to the Standing Committees of the American Society of Agronomy named above, President F. W. Parker has named a Committee on Arrangements for the 1944 meeting of the Society, which is to be held in Cincinnati, Ohio, as follows: R. D. Lewis, G. W. Conrey, R. E. Yoder, E. N. Fergus, and M. E. Weeks.

—A—

A committee on Selection of Fellows has also been named by President F. W. Parker, as follows: H. D. Hughes, O. S. Aamodt, and F. E. Bear.

—A—

Doctor L. D. Baver, President of the Soil Science Society of America, and Doctor F. W. Parker, President of the American Society of Agronomy, have named a joint committee of the two societies on the preparation of a folder explaining the purposes and advantages of the two organizations. The joint committee is as follows: J. D. Luckett, general chairman; for the Soil Science Society, H. J. Harper and G. W. Conrey; for the American Society of Agronomy, F. D. Keim and R. J. Garber.

Doctor H. E. Myers, Professor of Soils, Kansas State College, Manhattan, Kans., has been granted a 2-year leave of absence to serve as Agricultural Advisor to the Department of State. Since about November 1, Doctor Myers has been located at the American Legation at Cairo, Egypt, where he will work through parts of North Africa and the Near East. Hugh G. Myers, formerly located with the Division of Dry Land Agriculture at Garden City, Kans., has accepted a temporary appointment as Associate Professor of Soils at Kansas State College during Doctor H. E. Myers absence.

—A—

Doctor D. D. Hill has been named head of the Department of Farm Crops, Oregon State College, Corvallis, Ore., to fill the vacancy occasioned by the death of Professor G. R. Hyslop. Plans are under way to create a G. R. Hyslop memorial fund from which to support a research fellowship in farm crops.

—A—

According to an announcement from the Canadian Wartime Information Board, a saw-fly resistant wheat is in sight which will combine resistance to this destructive pest with reasonably good yield, acceptable milling and baking qualities, and resistance to rust. Losses from the saw-fly to Canadian farmers are estimated to have run as high as 50,000,000 bushels, and last year are reported to have been about 20,000,000 bushels.

—A—

According to *Science*, Doctor H. H. Bennett, chief of the Soil Conservation Service, U. S. Dept. of Agriculture, and Doctor Robert V. Allison of the Florida Agricultural Experiment Station, will receive the Carlos Manuel de Cestenes decoration from the President of Cuba at the 1944 meeting of the Cuban National Congress of Soil and Fertilizers in recognition of soil studies and investigations made in Cuba from 1924 to 1926.

—A—

A Committee on Cooperation with Foreign Scientists has been named by President F. W. Parker as follows: Richard Bradfield, H. K. Hayes, C. E. Kellogg, and O. S. Aamodt. Doctor Parker has also named Doctor Kellogg to represent the American Society of Agronomy on the National Agricultural Jefferson Bicentenary Committee.

JOURNAL

OF THE

American Society of Agronomy

VOL. 36 FEBRUARY, 1944 NO. 2

RELIABILITY OF THE LINE INTERCEPTION METHOD IN MEASURING VEGETATION ON THE SOUTHERN GREAT PLAINS[1]

KENNETH W. PARKER AND D. A. SAVAGE[2]

RANGE investigators and land administrators are faced with the problem of securing accurate information relative to the character and condition of the vegetation on range land. In order to manage intelligently this natural resource so that the beneficial and protective functions are safeguarded, methods of inventory which accurately portray conditions as they occur are necessary. In range management the grazing animal, together with the forage crop, may be employed as a measure of productivity. Usually the index used for improvement or deterioration of a specific area is based on the amount and quality of the range forage. Determination of yield and composition by the method of clipping and weighing the harvested material from randomly located sample plots has many desirable features but, unfortunately, other factors, chief of which is the amount of labor involved, precludes more general application. Among the more recent developments in field technic for the quantitative determination of botanical composition and percentage ground cover is the line interception method developed at the Southwestern Forest and Range Experiment Station[3] and described by Canfield (1).[4] The purpose of this paper is to report the result of tests made to determine the reliability of the line interception method as used in the sand-dune sage type on the Southern Great Plains.

---

[1]Contribution from the Southwestern Forest and Range Experiment Station, U. S. Forest Service, Tucson, Ariz., and the Division of Forage Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, in connection with range improvement work conducted on the Southern Plains Experimental Range, Woodward, Okla., by the Bureau of Plant Industry in cooperation with other federal agencies and the Oklahoma Agricultural Experiment Station. Received for publication February 24, 1943.

[2]Forest Ecologist, Southwestern Forest and Range Experiment Station, and Senior Agronomist, Division of Forage Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, respectively.

[3]Maintained by the Forest Service, U. S. Dept. of Agriculture, for Arizona, New Mexico, and west Texas, with headquarters at Tucson, Ariz.

[4]Numbers in parenthesis refer to "Literature Cited", p. 109.

DESCRIPTION OF THE METHOD

The method of measuring density, botanical composition, and frequency of occurrence of native vegetation on the Southern Plains Experimental Range at Woodward, Okla., is an adaptation of procedures used by Canfield (1), Tinney, *et al.* (9), and Levy (4). A preliminary description of the modified method was made by Savage (6) in 1940. It was adopted and tested to provide statistically reliable measurements of the characters listed above and their changes as affected by different systems and intensities of grazing in the future.

The method, as used at Woodward, consisted of measuring in centimeters the peripheral spread of the foliage cover of shrubs and the actual ground cover of all other species of vegetation directly under and parallel with a tightly stretched steel wire cable 3/64 inch in diameter and 10 meters long. This is U. S. Army field telephone cable wire from which the insulation has been removed. The cable contains 10 strands of fine steel wire wound tightly around a larger strand and can be rolled on a reel without kinking. A steel ring 1 inch in diameter is fastened to each end of the cable a few inches beyond balls of solder which are grooved with a file to indicate the ends of the 10-meter length. Through these rings are slipped round solid steel pins, ¾ inch in diameter and 44 inches long. The pins are sharpened at the lower end and equipped with large bolt heads at the top. They are driven firmly into the ground and used to stretch the wire tightly at the upper level of sand sagebrush, *Artemisia filifolia* Torr., and other shrubs.

As soon as the line transect is established in this manner and with the aid of an assistant to record the data, the range technician measures along the wire that portion of the foliage cover of all shrubs that lies within 5 centimeters of a vertical-plane projection of the wire. Used for this purpose is a Stanley No. 1266EM push-pull flat steel rule 2 meters long and graduated in centimeters. When branches of the shrubs are as close as or closer than 10 centimeters apart, they are considered to represent solid foliage cover. When their proximity to each other exceeds 10 centimeters, the various parts are measured independently and the spaces between considered as blanks. All branchlets of any one shrub measured in this manner are totalled by the technician and announced as one figure to the recorder. This provides a tabulated record of the foliage density and the actual number of plants of every shrub occurring on the line (within a strip 10 centimeters wide and 10 meters long).

After the shrubs are measured, they are pushed aside and the wire is lowered as close to the ground as possible. This is done with ease and dispatch by the technician and recorder working together and simultaneously slipping the rings down the pins at opposite ends of the wire. The next step consists of measuring immediately below and along the wire that portion of the actual ground cover of every species of grass, sedge, and forb that lies within ½ centimeter of a vertical plane projection of the wire, within a strip 1 centimeter wide and 10 meters long. These measurements are made most accurately by straddling the wire and using flat mild steel rules 40 centimeters long and ⅛ inch thick. The rules are notched with a file and numbered at centimeter intervals. They are ½ inch wide at the 40-centimeter end and taper to a blunt point at the zero end. The rule is polished to facilitate reading and, because of its rigidity and tapering point, may be pushed with ease along the ground through the crowns of dense plants.

When the ground surface parts of any herbaceous plant situated along and beneath the wire are as close as or closer than 1 centimeter apart, they are considered to occupy the soil surface completely, to represent solid ground cover. One

centimeter is arbitrarily allowed as the ground surface measurement for every single-culmed species whose diameter is less than 1 centimeter. Since this often gives to such plants an actual space nearly ½ centimeter on either side of the culm, a corresponding space ½ centimeter long is arbitrarily allowed to each side of the ground surface periphery of plants having several stems or other ground surface portions situated close enough together to constitute solid cover. When the basal portions of any one plant are farther apart than 1 centimeter, they are measured separately and the space between is considered a blank. These separate measurements for one plant are totalled by the technician and recorded as one figure on the transect sheet, which thereby provides a complete record of density and actual number of plants occurring on the line.

Other data recorded in connection with each line are the general soil texture, location with respect to dunes, and direction and degree of slope checked by occasional use of a compass and slope meter. A sample copy of a line-transect recording sheet, showing data recorded in the field and summaries made in the office, is presented as Table 1. It is a simple matter to total the centimeter readings for each species and thereby obtain a direct reading of its percentage of density on the 10-meter line by setting off one decimal point in the sum. The botanical composition or percentage of total vegetation represented by each species is easily computed from this record. The number of centimeter readings in each column automatically shows the number of plants present on the line. The numbers provide the basis for determining frequency of occurrence of species.

Each pasture was divided into five strata with two series of alternate 10-meter transect lines located in each stratum. The readings were made on one of the series in every pasture before reading the second group of lines which made it possible to study all pastures under more nearly comparable weather conditions. The data were then calculated to determine the number of additional 10-meter lines required to reduce the error of variation in total perennial grass below the mean error of 6%. The required number of additional lines was then read as a third randomized series in each stratum. This procedure was changed in 1942 when each pasture was divided into 10 strata and one series of randomized transect lines located at alternate 10-meter intervals in each stratum. The recording work is done most advantageously with two two-man crews working on every other 10-meter transect line. After the first crew has its pins set in line according to randomized location and by compass direction, the second measures its location and sights in its pins along the same line. Thereafter, the pins of one crew are used by the next crew to keep its pins in line.

Two two-man crews have been used to conduct most of the line-transect work on the Southern Plains Experimental Range since these studies were started in 1940. In order to maintain a standardized procedure in reading densities, each technician rechecks his own readings and that of his co-technician at the start of work each morning and afternoon. Another series of similar checks are made during the course of the work in the mornings and afternoons. Lines are selected at random for this purpose by the recording assistants and the technicians are notified of the selection after the first reading is made. By following this procedure each technician is cognizant of the fact that any reading he makes may be subject to recheck by himself and his co-technician. With considerable practice of this kind each man was able to duplicate his own readings and those of the other man with a surprisingly high degree of consistency except when the steel wire was accidentally moved during the course of the work. Whenever a reading was made

TABLE 1.—*Line transect recording sheet.*

LIME TRANSECT RECORDING SHEET Sheet No.______

Southern Plains Experimental Range, Southern Great Plains Field Station

Woodward, Oklahoma Examiner: Solomon, R. E.

Pasture No. 17; Strata No. 3; Line transect No. 15: Date June 10, 1940

Location with reference to dunes: top: near side: X Low place vs. dunes:__________

Slope: Direction SE: Per cent 5: Approx. soil texture: Loamy fine sand

Spp. symbol	Scr	Bgr	Asc	Aha	Etr	Pvi	Bcu	Bhi	Pst	Tpu	Ppu	Mpe	Ean	Ccr	Afi	Grand total
	3	2	4	3	2	2	3	2	2	1	1	1	1	1	57	
	2	1	3	2	1	3	4	3		1	1	1	1	1	62	
	3	3		3						1	1	1		1	8	
	5	2								1	1	1		1	17	
	5	4								1	1			1	93	
	1	1								1	1			1	18	
	2	3									1			1	18	

	1	2									1			1	12	
	3	1									1				9	
	2										1				8	
															11	
															18	
															14	
															5	
															29	
Total % density	2.7	1.9	0.7	0.8	0.3	0.5	0.7	0.5	0.2	0.6	1.0	0.4	0.2	0.8	37.9	49.2
Per cent comp.	5.5	3.9	1.4	1.6	0.6	1.0	1.4	1.0	0.4	1.2	2.0	0.8	0.4	1.6	77.0	100.0
No. of plants	10	9	2	3	2	2	2	2	1	6	10	4	2	8	15	78

without any lateral movement of the wire, the results could be duplicated accurately by the same technician and his co-technician.

THE SAND-DUNE SAGE TYPE

The sand-dune sage type which characterizes the experimental range consists mostly of gently rolling stabilized dunes frequently interspaced with areas of heavier soil and clad uniformly as a whole with highly variable amounts of sand sagebrush, grass, and other vegetation. Nearly every square rod of land supports from one to a dozen or more plants of sand sagebrush which gives the landscape a typical grey appearance. Represented on the area are over 50 species of grass and 216 species of forbs and shrubs. Most of the grasses are bunch types which usually present a thin open stand associated with the other species of vegetation. A dense shortgrass turf predominates to the exclusion of brush only on small areas of heavy soil between the dunes. The density of brush and forbs usually increases and that of grass declines with successive increases in slope and depth of sand. The vegetation, therefore, constantly changes with topography throughout the area but, when considered as a whole, is surprisingly uniform within different sets of pastures.

The average density of all vegetation on the 20 pastures, as determined from 3,729 10-meter transect lines in 1940, was 34.3% (Table 2). The percentage of total vegetation represented by blue grama, *Bouteloua gracilis* (H.B.K.) Lag., was 6.34%; sand dropseed, *Sporobolus cryptandrus* (Torr.) A. Gray., 5.25%; other perennial grass, 2.42%; annual grass, 0.90%; all grass, 14.91%; sand sagebrush, 79.2%; other brush, 4.88%; and all forbs, 0.99%. Blue grama occupied 42.5% of the total grass cover; sand dropseed, 35.2%; other perennial grass, 16.2%; and annual grass, 6.0%. Fig. 1 shows the average density and botanical composition of native vegetation on the experimental range, and represents a graphic illustration of the manner in which the results of line-transect data may be presented.

TABLE 2.—*Average density on 20 pastures as determined by the line-transect method in 1940.*

Blue grama, %	Sand drop-seed, %	Perennial grass		Annual grass, %	Total forbs, %	Sage-brush, %	Other brush, %	Total vege-tation, %
		Others, %	Total, %					
2.2	1.8	0.8	4.8	0.3	0.3	27.2	1.7	34.3

The presence of numerous shrubs, the highly variable nature of the vegetation, and the constantly changing topography add to the problems involved in studying vegetation on the experimental range. The chartograph method described by Hanson (3), Sarvis (5), Savage and Jacobson (7), and others is not adapted for accurate use on vegetation of this kind. Meter quadrats are too limited in scope to represent accurate sampling areas for highly variable brush-infested vegetation and slopes. A pantograph table would have to be located above the brush and too far from the ground surface to permit

strictly accurate readings. The line transect method appears to be admirably adapted to the situations encountered on the experimental range. It represents a desirable combination of speed and accuracy. Each line provides a sample through and between several shrubs and over a constantly changing topography.

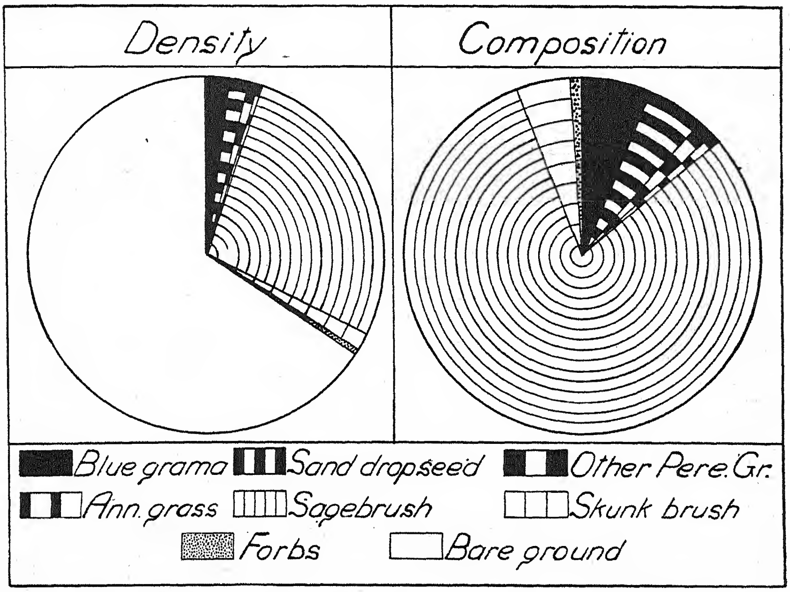


FIG. 1.—Average density and botanical composition of native vegetation on the Southern Plains Experimental Range in 1940, as determined by the line interception method on 3,729 10-meter transect lines.

PROCEDURE IN TESTING METHOD

Inasmuch as the above-described method had never been previously used in the sand-dune sage type of the Southern Great Plains, it seemed advisable to test the accuracy and reliability of the method prior to extensive use in procuring data on experimental pastures. In order to determine whether or not different individuals could measure the same lines in a similar manner, four men in random order recorded the vegetation on the same transect lines. Also, each man repeated at random his measurement of each line in order to determine the variation of any one individual. Three men of the group were relatively inexperienced with the method, having had only 1 day's previous training. The fourth man (No. 4 in the tables) provided the necessary instruction. All measurements were recorded in the metric system. Each transect line was 10 meters long and 18 lines were recorded. Sagebrush was found on 17 of the lines.

ANALYSES OF RESULTS AND DISCUSSION

In making measurements of vegetation by the line interception method, plants are arbitrarily observed and recorded in one of four

categories as follows: (a) Perennial grasses, (b) annuals (weeds and grasses), (c) shrubs (browse), and (d) perennial weeds. The manner in which each of these groups of plants is measured has been previously described and is based on growth characteristics peculiar to each category. Since perennial weeds were present only in minor amounts, the data were considered of no value for ascertaining the reliability of the line interception method and hence are not considered in this paper.

PERENNIAL GRASSES

Ten species of perennial grass were encountered in measuring the 18 lines. The principal species, blue grama and sand dropseed, were found to comprise the major portion of this category. The average composition of perennial grasses computed on the basis of density as measured independently by the four men on 18 randomly located lines is presented in Table 3. The differences between individuals is not considered too great for the purpose of making an inventory of the vegetation of an experimental pasture. The differences which are apparent between individuals are probably due to the following causes: (a) Failure to measure identical plants in a similar manner, (b) differences in judgment as to whether a plant is either completely or partially on or off the line and, (c) misidentification as to plant species. Such causes can only be reduced by training and continuous effort on the part of the individual to improve his technic. Table 3 illustrates the error due to misidentification; for example, No. 3 and No. 4 failed to recognize hairy grama, *Bouteloua hirsuta* Lag., which they undoubtedly recorded as blue grama. If flower stalks had been present there would have been little or no excuse for this error; however, when segregation has to be made on the basis of vegetative characters there is apt to be confusion between these two species.

TABLE 3.—*Average percentage composition of perennial grasses on basis of density as measured independently by four men on 18 randomly located lines.*

Species	Man 1	Man 2	Man 3	Man 4
Andropogon hallii	2.08	2.28	2.33	2.67
Andropogon scoparius	2.55	2.18	1.90	1.33
Bouteloua curtipendula	0.28	0.37	0.78	0.57
Bouteloua gracilis	45.47	42.57	46.90	51.57
Bouteloua hirsuta	1.32	0.91	—	—
Buchloe dactyloides	—	0.18	0.26	0.29
Eragrostis trichodes	1.32	0.82	0.60	0.38
Panicum virgatum	1.32	0.73	1.03	0.86
Poa arachnifera	1.04	1.73	1.03	0.38
Sporobolus cryptandrus	44.62	48.23	45.17	41.95
Total	100.00	100.00	100.00	100.00

The measurements of all perennial grasses expressed in percentage of ground cover made by four individuals on 18 10-meter transect lines are presented in Table 4. Replicates of each individual are recorded in columns A and B.

TABLE 4.—*Comparison of four individuals' measurements of perennial grasses on 18 10-meter lines replicated (A and B) by each individual.*

Line No.	Man 1		Man 2		Man 3		Man 4	
	A	B	A	B	A	B	A	B
1	6.3	6.1	6.4	7.1	8.0	8.0	5.7	6.5
2	4.0	3.7	4.1	3.1	4.4	4.3	3.9	4.4
3	18.5	19.6	19.5	16.4	20.4	19.6	17.5	18.1
4	8.6	10.3	8.0	10.5	10.3	10.6	8.2	10.2
5	9.8	9.5	9.5	9.4	10.0	9.2	8.0	8.4
6	5.6	5.4	5.9	6.4	6.2	6.2	5.1	6.0
7	2.9	3.0	3.6	2.7	2.7	3.5	2.8	2.5
8	3.2	2.5	3.0	3.3	3.6	3.1	4.2	3.2
9	2.5	2.2	2.4	2.8	2.3	3.1	2.4	2.7
10	5.9	5.2	5.3	6.5	6.2	5.6	5.2	5.6
11	12.5	12.7	12.4	12.7	14.2	13.1	12.6	12.9
12	5.0	5.1	6.1	5.4	5.1	5.2	6.0	5.7
13	8.0	7.6	8.3	8.8	8.3	8.6	8.8	8.1
14	5.7	5.3	5.4	5.5	6.3	5.7	5.2	5.1
15	3.6	3.9	4.3	4.9	3.7	3.9	3.9	3.9
16	2.0	1.9	3.2	3.4	2.4	2.4	2.3	2.0
17	0.5	0.7	0.8	1.1	0.8	1.1	1.1	0.9
18	1.6	1.5	1.4	1.8	1.2	1.5	1.6	1.9
Total......	106.2	106.2	109.6	111.8	116.1	114.7	104.5	108.1
Mean......	5.9	5.9	6.1	6.2	6.4	6.4	5.8	6.0

Regular analysis of variance procedure[5] for split-plot design was applied to the data presented in Table 4 with the results shown in Table 5.

TABLE 5.—*Analysis of variance.*

Source	D.F.	S.S.	M.S.
Among Men			
Between lines....................	17	26668.8575	156.9916**
Between men......................	3	6.3655	2.1218**
Interaction: Lines × men..........	51	20.0570	.3933 error (a)
Total among men...............	71		
Among Measurements, Same Man			
Between A and B..................	1	.1344	.1344
Interaction: Men × (A, B).........	3	.4145	.1382
Interaction: Lines × (A, B)........	17	7.5081	.4416
Interaction: Men × lines × (A, B)..	51	12.5330	.2457 error (b)
Total among measurements........	143	2715.8700	

**Significant at the 1% level.

It would appear that there is not a significant difference between a man's first estimate (A) of the same line and his second estimate (B). In other words, two measurements of the same line by the same

[5]Procedure suggested by Professor F. X. Schumacher, Duke University, Durham, N. C.

man are satisfactorily consistent. In view of this it would appear possible to depict accurately the vegetational trend both as to density and floristic composition during the course of a treatment (such as grazing) provided the same lines (which might be located with permanent stakes) were remeasured intermittently by the same individual. Thus, any differences appearing between two sets of measurements would be due largely to treatment, plus error of measurement, which insofar as any one individual is concerned is not biased and appears to be negligible. It is possible that an individual can develop bias in the interim between measurements; it is believed, however, that this can be prevented by strict adherence to written definitions and rules as to how the measurements should be taken.

Some difference of opinion exists among range technicians as to whether or not it is possible to return to and to remeasure exactly the same line. Theoretically this may not be true. But it should be remembered that the transect line is in reality a long, narrow plot 1 centimeter wide in the case of perennial grasses and forbs and 10 centimeters wide in the measurement of shrubs, so that if proper precautions are taken in keeping a straight, taut line there should be little difficulty in relocating approximately the same line, especially in vegetational types predominantly grass. If the same lines were not remeasured but the area sampled with a new set of randomly located lines, differences in means would be ascribable to treatment, plus error of sampling, plus error of measurement. Obviously, the error of sampling could be reduced by measuring a greater number of lines. It should be recognized that if the same lines are not relocated the sampling error alone would be greater than the variation among men. In this respect it should be noted in Table 5 that the mean square between lines greatly exceeds the mean square between men. In sand-dune sage vegetation it does not appear wise to attempt to return to the same line locations because some of the shrub branches may be broken and subsequently destroyed when the transect line is pushed to the ground in order to measure the surface herbaceous vegetation.

The analysis indicates a significant difference between individuals in measuring the same lines (a difficulty inherent with all methods of measuring the density of range vegetation). Hence, if different men measure the same set of lines—as might occur in resampling plots—the variation among their measurements is subject to the variance listed as error (a) in Table 5. However, the difference between men is not great. The mean of man 1 (Table 4) is 5.9 and of man 3, 6.4; a variation of 8.47%. If the difference is no greater than this, it should not be a serious objection to the method since the general objective in measurement is to establish the effect of time or intensity of grazing use on density of range vegetation. For example, it is expected that under prolonged heavy grazing use the actual difference in density of perennial grasses will be great as compared to measurement differences between men.

It is noteworthy that three (Nos. 1, 2, and 3) of the four men who made the test had never previously used the line interception method of measuring vegetation. If it had not been for man 3 who was con-

sistently high as compared with the other technicians (significantly so when compared with man 1), there would have been no significant difference among men. The need for repeated periodical checks is indicated. It would seem logical that if the test had been made subsequent to a period of a week or 10 days intensive training that there would have been less differences in the measurements between men.

In sampling pastures where the investigator is interested in the present condition and not testing any difference due to treatment and where several men are used in the sampling, then each man should measure a proportionate number of lines as measured by the group. The error of measurement will of course be subject to error (a), but any differences in standards will be averaged out in the group.

ANNUALS (WEEDS AND GRASSES)

Annual plants, both weeds and grasses, were not measured but recorded simply by counting the numbers of each species found to occur on the line. In this respect the line interception method is similar to that of Stone and Fryer (8), except that the plants must be rooted within the transect. The principal species encountered were *Festuca octoflora* Walt., *Plantago purshii* R. & S., *Chenopodium leptophyllum* Nutt., *Lepidium densiflorum* Schrad., *Cryptanthe crassisepala* (T. & G.) Greene, *Eriogonum annuum* Nutt., and *Monarda pectinata* Nutt. The total number of annual plants observed independently by the four men on 18 lines is presented in Table 6. Replicates of each individual's count are recorded in columns A (first count) and B (second count).

Examination of Table 6 reveals that, as in the measurements of perennial grasses, differences between individuals on identical lines are apt to vary. Although, in general, a man's first count (A) will closely coincide with his second count (B), there may be a wide discrepancy on some lines; for example, man 1 on line 12 first counted five plants and on his second count observed 15. An explanation of these differences between men and between a man's first and second estimate may be accounted for in part. During the course of the field work it was observed that in spite of the greatest care both the steel transect wire and plants were frequently disturbed by accidental trampling. Measurements and concurrent counts of the same line by different individuals were made in random order. If the test were to be repeated, it is suggested that record be kept of this order so that it might be possible to detect and remove the differences arising from this source. It is also suggested that the test be made at a time of year when the plants are in a more advanced stage of growth so that they can better withstand the repeated handling required in measurement.

SHRUBS (BROWSE)

Sand sagebrush is the principal component of the sand-dune sage community. Although other species of shrubs occur in this community, none were encountered on the measured lines. Sand sagebrush was observed on all but one of the 18 lines. The measurements of sand sagebrush as recorded by each man on each of the 17 10-meter

TABLE 6.—*Total numbers of annual plants (weeds and grasses) observed independently by four men on 18 randomly located lines, replicated (A and B) by each individual.*

Line No.	Man 1		Man 2		Man 3		Man 4	
	A	B	A	B	A	B	A	B
1	5	6	6	6	5	7	4	5
2	10	10	12	11	15	12	11	11
3	17	23	16	15	21	22	17	18
4	21	24	23	26	26	27	27	26
5	20	20	16	10	16	11	19	20
6	8	5	8	5	10	9	7	8
7	13	11	11	8	10	8	8	7
8	5	6	7	6	2	4	3	4
9	10	10	6	10	8	8	5	6
10	8	8	10	8	12	5	9	9
11	7	10	11	11	13	13	11	9
12	5	15	8	11	10	8	7	7
13	20	21	19	19	21	19	19	21
14	7	8	6	5	9	13	8	6
15	7	4	6	5	5	5	5	5
16	9	10	8	8	7	11	6	7
17	8	5	5	5	7	8	6	8
18	16	15	16	12	17	17	16	18
Total......	196	211	194	181	214	207	188	195
Mean......	10.89	11.72	10.78	10.06	11.89	11.50	10.44	10.83

length lines are presented in Table 7. Replicate measurements for each man are indicated in columns A and B.

TABLE 7.—*Comparison of four individuals' measurements of sand sagebrush on 17 10-meter lines replicated (A and B) by each individual.*

Line No.	Man 1		Man 2		Man 3		Man 4	
	A	B	A	B	A	B	A	B
1	22.6	24.7	20.8	20.5	23.1	23.4	21.4	22.1
2	29.4	30.0	28.1	27.5	25.4	27.5	24.7	28.5
3	4.2	3.3	3.3	4.7	3.0	2.8	3.3	3.1
4	7.2	4.9	5.9	4.5	7.7	6.8	6.7	5.5
5	30.7	30.7	30.5	31.4	26.5	30.1	29.7	29.8
6	36.7	35.0	38.3	36.2	40.5	38.1	31.3	33.6
7	53.2	53.3	49.9	50.5	46.3	50.8	52.9	52.1
8	48.0	47.7	49.2	47.4	51.0	52.5	47.6	47.6
9	28.2	28.5	25.9	25.8	30.9	29.0	27.9	27.5
10	29.8	27.5	20.2	24.8	26.2	21.7	21.6	22.7
11	42.3	43.1	40.8	39.1	40.8	41.1	38.7	41.8
12	31.0	30.3	29.5	30.7	38.2	37.9	29.7	29.9
13	36.2	38.0	39.5	37.5	45.7	44.1	41.5	41.1
14	54.6	55.7	49.2	53.5	58.7	56.6	53.7	52.0
15	38.9	38.0	37.0	39.9	45.4	42.1	35.2	35.6
16	60.2	59.2	62.3	61.9	61.2	61.3	57.4	57.2
17	29.6	28.8	28.7	28.5	29.7	30.1	28.8	29.4
Total......	582.8	587.7	559.1	564.4	600.3	595.9	552.1	559.5
Mean......	34.3	34.0	32.9	33.2	35.3	35.0	32.5	32.9

The data presented in Table 7 were handled in accordance with the regular analysis of variance procedure for a split-plot design similarly utilized for the analysis of perennial grass data and are summarized in Table 8.

TABLE 8.—*Analysis of variance.*

Source	D.F.	S.S.	M.S.	
	Among Men			
Between lines	16	30261.3724	1891.3358**	
Between men	3	130.3100	43.4367**	
Interaction: Lines × men	48	400.2000	8.3375	error (a)
Total among men	67			
	Among Measurements; Same Man			
Between A and B	1	.1297	.1297	
Interaction: Men × (A, B)	3	3.3709	1.1236	
Interaction: Lines × (A, B)	16	19.2303	1.2019	
Interaction: Men × lines × (A, B)	48	88.6091	1.8460	error (b)
Total among measurements	135	30903.2224		

**Significant at the 1% level.

Two principal findings are apparent as was the case with the analysis of data for perennial grasses, that in the measurement of sand sagebrush there is (a) no significant difference between an individual's first measurement (A) and his second (B) of the same line, and (b) a significant difference between individuals measuring the same line. It is also apparent that, although shrubs are measured by crown spread intercepted, the conclusions appertaining to the measurement of perennial grasses, wherein the measurements are obtained at ground level, are also in order. It also appears that the greatest variation between individuals may occur on lines with the least vegetation; for example, lines 3 and 4, Table 7. Hence, if a longer line had been measured there would probably have been less difference between the means obtained for these lines since more vegetation would have been measured. This would indicate the desirability of a study to determine the most efficient length of line for sampling vegetation in the sand-dune sage community.

SUMMARY AND CONCLUSION

The line-transect method of determining density and botanical composition of native vegetation, when kept carefully standardized by repeated checking of procedures, represents a desirable combination of speed and accuracy. The technic appears to be admirably suited for use on the sand-dune sage type of the Southern Great Plains.

LITERATURE CITED

1. CANFIELD, R. H. Application of the line interception method in sampling range vegetation. Jour. For., 39:388–394. 1941.
2. DAVIS, W., *et al.* Methods of pasture analysis. Agr. Prog., 10:3–30. 1933.

3. HANSON, H. C. A comparison of methods of botanical analysis of the native prairie in western North Dakota. Jour. Agr. Res., 49:815–842. 1934.
4. LEVY, BRUCE. Technique employed in grassland research in New Zealand. Imp. Bur. Plant Gen. Herbage Plants Bul. 11. 1933.
5. SARVIS, J. T. Effects of different systems and intensities of grazing upon the native vegetation at the Northern Great Plains Field Station. U.S.D.A. Bul. 1170. 1923.
6. SAVAGE, D. A. The line-transect method, an improved method of studying native range vegetation. U.S.D.A. Mimeographed leaflet. 1940.
7. SAVAGE, D. A., and JACOBSON, L. A. The killing effect of heat and drought on buffalo grass and blue grama grass at Hays, Kansas. Jour. Amer. Soc. Agron., 27:566–582. 1935.
8. STONE, W. C., and FRYER, J. R. A botanical study of pasture mixtures. Sci. Agr., 15:777–805. 1935.
9. TINNEY, FRED W., AAMODT, O. S., and AHLGREN, HENRY L. Preliminary report of a study on methods used in botanical analyses on pasture swards. Jour. Amer. Soc. Agron., 29:835–840. 1937.

INFLUENCE OF FERTILIZER, FERTILIZER PLACEMENT, SOIL MOISTURE CONTENT, AND SOIL TYPE ON THE EMERGENCE OF SOYBEANS[1]

A. H. PROBST[2]

A FACTOR of great importance in the continued economical production of soybeans in view of the vast expansion in soybean acreage and the constant decrease in fertility of the soil, is the application of mineral fertilizers to soybeans under those conditions that warrant their use.

Since soybeans are frequently impeded in germination and emergence by mineral fertilizers, it is of importance to know what kind and amount of fertilizer may be applied and under what conditions, without injurious effects to the germinating seed and the young seedlings.

Studies were conducted at Lafayette, Ind., by the U. S. Regional Soybean Industrial Products Laboratory[3] and Purdue University Agricultural Experiment Station cooperating, from 1939 to 1941, inclusive, to determine (a) the influence of kind and rate of application of fertilizers, (b) fertilizer placement, (c) soil moisture content, and (d) soil type on the emergence of soybeans.

Considerable decreases in stands were obtained by Barnes (1)[4] when mineral fertilizers were drilled in contact with soybean seed, but when applied separately from the seed stands were only slightly reduced.

The effect of Ammo-Phos (13–48–0) upon seed germination and plant growth of a number of crops was studied by Coe (2). He obtained very pronounced fertilizer injury to germination and some retardation in emergence when Ammo-Phos was applied in contact with soybeean seed, even in small quantities, but little or no injury or retardation when applied ½ inch or 1 inch away from and on the same level as the seed. Various fertilizer mixtures applied in direct contact with soybean seed in field studies were quite injurious to germination even in relatively small quantities. Some fertilizer mixtures were more injurious than others. From studies with the several crops worked with he found moisture content a more important factor affecting germination than soil type, and the greater the moisture content in a given soil, the larger the amount of fertilizer required to injure germination. Horizontal diffusion of fertilizers was found to be very slow.

---

[1]Contribution from the Division of Forage Crops and Diseases, Bureau of Plant Industry, Soils, and Agricultural Engineering, Agricultural Research Administration, and Bureau of Agricultural and Industrial Chemistry, U. S. Regional Soybean Industrial Products Laboratory, U. S. Dept. of Agriculture, and Purdue University Agricultural Experiment Station, Lafayette, Indiana, cooperating. Journal Paper No. 48, Purdue University Agricultural Experiment Station. Received for publication March 26, 1943.

[2]Assistant Agronomist.

[3]A cooperative organization participated in by the Bureaus of Agricultural and Industrial Chemistry, and Plant Industry, Soils, and Agricultural Engineering, Agricultural Research Administration, of the U. S. Dept. of Agriculture, and the agricultural experiment stations of the north central states of Illinois, Indiana, Iowa, Kansas, Michigan, Minnesota, Missouri, Nebraska, North Dakota, Ohio, South Dakota, and Wisconsin.

[4]Figures in parenthesis refer to "Literature Cited", p. 119.

Hutcheson and Wolfe (3) found that soybeans planted in Hagerstown silt loam were substantially lowered in germination by all fertilizers used except acid phosphate, and that injury was less pronounced, when evident, on Norfolk sandy loam than on the Hagerstown soil. They found row applications more harmful than broadcast applications. At a later date these same investigators (4) reported that fertilizers applied to a sandy loam soil in direct contact with soybean seed had no appreciable detrimental effect on germination. Both of the above studies were conducted in the greenhouse in flats 1 foot square.

Parker and Oliver (5), working with bean, pea, and cabbage seeds, found that under quite low soil moisture conditions, fertilizers mixed with the soil were more injurious to germination than those placed in a band 2-inches beneath the seed, and that, when placed 2-inches to the side and 2-inches below the level of the seed, fertilizers were relatively non-injurious, irrespective of soil moisture content.

Sayre and Clark (6) obtained reduced germination with applications of phosphate and potash applied in direct contact with the seed at the time of planting wax beans. They also pointed out that the rate of application of fertilizers is of great importance in the amount of injury to germination and that there is exceedingly limited lateral movement of fertilizers.

The effect of fertilizers on germination of corn and cotton seeds was studied by Sherwin (7) on four different soils and he reports that, "The class of soil used has appeared to bear no relation to the effect of the fertilizers." He also found that germination is generally inhibited by the presence of fertilizers and that the inhibition is greater when the fertilizer is in direct contact with the seed than when it is mixed with the soil.

Walker and Mulvey (8) reported a greater retardation in emergence of soybean seedlings when the fertilizer was applied with a grain drill, in rows 7 inches apart, at seeding time than when the same amount per acre was applied with a corn planter which placed the fertilizer in bands on each side of the seed in rows 34 inches apart. Phosphate alone had the least retarding effect.

MATERIALS AND METHODS

Emergence studies were conducted both in the field and in the greenhouse during the 3-year period, 1939 to 1941, with Dunfield, a yellow-seeded variety of soybeans.

Fertilizer treatments equivalent to 0–20–0, 0–0–20, and 0–20–20 were applied at rates ranging from 125 to 750 pounds per acre by 125-pound increments in comparison with no fertilizer, as shown in Table 1. Commercial 20% superphosphate and 50% muriate of potash were used in compounding the fertilizers. The concentration of fertilizer nutrients applied per foot of row in either the field or the greenhouse studies was equal to that obtained when soybeans and fertilizers are drilled together with a grain drill which spaces the rows 8 inches apart. At the 125-pound per acre rate the quantity of fertilizer per foot of row was 0.86 gram of 0–20–0, 0.34 gram of 50% muriate of potash to give the nutrient equivalent of 0–0–20, and 1.20 grams of the above materials in combination to give the nutrient equivalent of 0–20–20.

The fertilizer was applied (a) in contact with the seed, the seed being placed on the fertilizer, and (b) in narrow bands 1 inch to each side of the seed and on the same level as the seed. The fertilizer bands were about 3/8 inch wide. The placement of fertilizer and seed in the field studies is shown in Fig. 1.

FIELD STUDIES

The field studies were made on Brookston silty clay loam at Lafayette, Ind., with two dates of planting to obtain varying soil moisture contents at the time of planting. The soil moisture content over the 3-year period approximated 15.0% and 22.0%, calculated on the dry soil basis, in the upper 8 inches of soil at the time of planting for the low and high moisture conditions, respectively. No precipitation of any consequence occurred in any year immediately after planting.

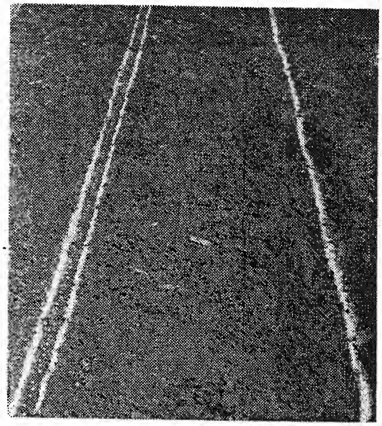


FIG. 1.—Placement of fertilizer and seed in the field study. Fertilizer placed in narrow bands 2 inches apart with the seed between the bands on the left and in contact with the seed on the right, each at the rate of 750 pounds per acre of 0–20–20.

The planting dates were June 26, June 5, and June 24 for the high soil moisture conditions and May 27, July 9, and July 21 for the low soil moisture conditions, respectively, for 1939, 1940, and 1941. The mean maximum and mean minimum temperatures for the 10-day period including and following the date of planting under high soil moisture conditions were 88.2° and 68.0°, 85.7° and 67.1°, and 89.5° and 67.7° F, and for the low soil moisture conditions they were 82.3° and 62.8°, 85.6° and 60.3°, and 93.7° and 70.6° F, respectively, in 1939, 1940, and 1941.

A modified Latin square design with four replications of each treatment was used each year. Two-hundred seeds of Dunfield soybeans were uniformly distributed in rows 18 feet long and 30 inches apart. The seed and fertilizer were covered uniformly with soil to a depth of about 1 inch and lightly compacted.

Adjacent blocks of land were used for the two different soil moisture levels and the seed bed was prepared, except for plowing, the day prior to planting.

The rapidity of emergence, as influenced by fertilizer and placement treatments on the high soil moisture level only, was measured by expressing the number of plants emerged by the seventh day after planting as a percentage of the final number emerged on the same plot.

GREENHOUSE STUDIES

The same kinds and rates of application of fertilizers were used in the greenhouse as in the field.

Two soil types were used in the greenhouse, namely, Brookston silty clay loam which is relatively fertile with a fairly high organic matter content and a pH of about 6.8 to 7.0, and Clermont silt loam which is relatively infertile with a low organic matter content and a pH of about 4.5.

Two soil moisture levels were maintained on each soil type. Brookston was maintained at about 15% and 25% moisture and Clermont at about 15% and 20% moisture, calculated on the dry soil basis. Since the Clermont soil has a lower moisture capacity than the Brookston soil, the latter was maintained at a greater high moisture level.

The soil was placed to a depth of about 5 inches in water-tight greenhouse bench compartments and brought to the desired moisture content prior to planting. Periodic soil moisture determinations were made and water was added as needed by surface sprinkling.

Rows 25 inches long and 3 inches apart were marked off by compressing the soil with a V-shaped template. Fertilizer was applied uniformly in the bottom of the row and the seed placed on the fertilizer. Because of the narrow bottom of the furrow, the fertilizer was in a somewhat narrower band and consequently more concentrated than when applied in the field. Fifty Dunfield soybean seeds were planted per row and covered with about 1 inch of soil.

The two soils were arranged in a Latin square for each moisture level and the fertilizer treatments were randomized with two replications. The two moisture levels were adjacent. Fig. 2 shows the arrangement of the soil plots and a view of the young plants.

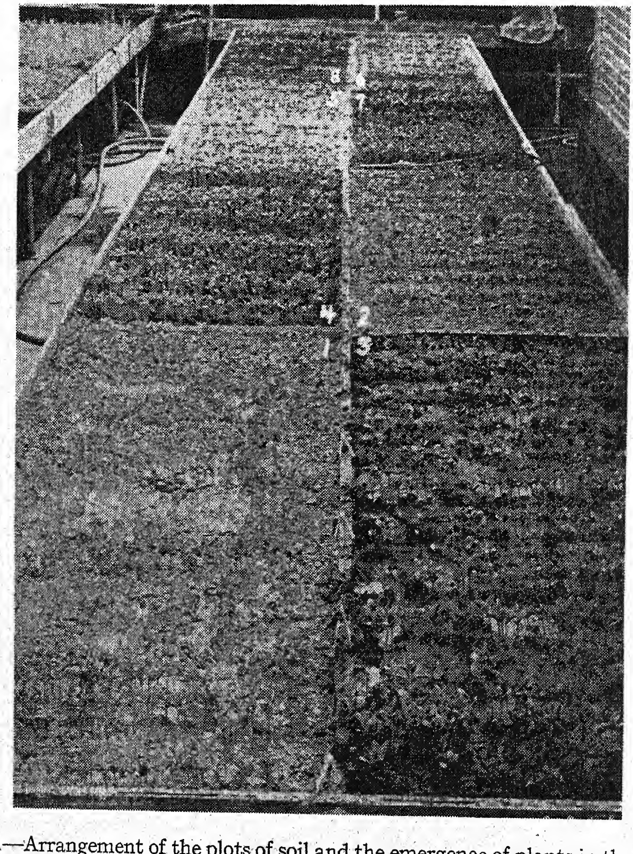


FIG. 2.—Arrangement of the plots of soil and the emergence of plants in the greenhouse studies. Plots 1 and 2 and 5 and 6 contain Clermont soil with 20% and 15% moisture, respectively, for each of the pairs; plots 3 and 4 and 7 and 8 contain Brookston soil with 25% and 15% moisture, respectively, for each of the pairs.

The greenhouse studies were made in midsummer. The mean maximum and mean minimum air temperatures in the greenhouse in the course of these experiments were 102° and 68°, 90° and 62°, and 85° and 61°F, respectively, in 1939, 1940, and 1941.

EXPERIMENTAL RESULTS

The 3-year summary of the field and greenhouse studies on the influence of fertilizer, fertilizer placement, soil moisture content, and soil type on emergence of soybeans, and the analysis of variance of certain treatments are presented in Table 1. Since there was a very wide range in percentage of emergence between treatments and since the data are discrete, the analysis of variance was made only for the unfertilized and 125-, 250-, and 375-pound per acre fertilizer treatments in contact with the seed and for all fertilizer treatments applied in bands. The influence of fertilizer and placement treatments on soybean emergence at different moisture levels on Brookston soil in the field is shown graphically in Fig. 3.

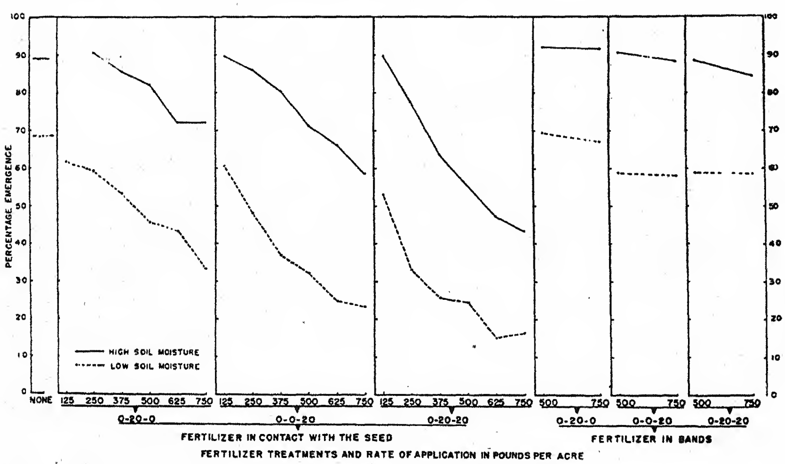


FIG. 3.—Field studies of the influence of fertilizer and its placement on soybean emergence at two soil moisture levels on Brookston silty clay loam. Each percentage point is a mean of three years' data, 1939–41.

The data in Table 1 show, with the exception of a few cases, that there is some reduction in emergence of soybean seedlings when fertilizer is applied in contact with the seed irrespective of soil moisture content or soil type and that this reduction in emergence tends to be somewhat proportional to the amount of fertilizer applied. Phosphate applied alone is usually less injurious to emergence than potash applied alone, and in combination these elements show cumulative deleterious effects.

Although some reduction in emergence was evident in all but a few cases when fertilizer was applied in contact with the seed, there was not a significant decrease in emergence due to applications as large as 375 pounds per acre of 0–20–0 or 0–0–20 fertilizer, or of 125

TABLE 1.—*Three-year summary, 1939–41, of field and greenhouse studies on the influence of fertilizer, fertilizer placement, soil moisture content, and soil type on emergence of soybeans, and the analysis of variance of certain treatments.*†

Mean percentage emergence for 3-year period, 1939–41

Fertilizer treatments, pounds per acre equivalent‡	Field studies, Brookston soil		Greenhouse studies			
			Brookston soil		Clermont soil	
	Low soil moisture	High soil moisture	15% soil moisture	25% soil moisture	15% soil moisture	20% soil moisture
None	68.2	88.8	92.0	92.7	97.0	97.3
125 lbs. 0–20–0 contact	61.9	92.4	84.0	90.0	91.3	97.7
250 lbs. 0–20–0 contact	59.1	90.4	76.7	85.0	82.0	86.0
375 lbs. 0–20–0 contact	53.3	85.2	56.0	81.7	75.0	82.3
500 lbs. 0–20–0 contact	45.9	82.2	49.0	68.0	62.3	73.3
625 lbs. 0–20–0 contact	43.7	74.5	43.3	63.0	46.3	67.3
750 lbs. 0–20–0 contact	33.6	74.5	28.0	58.3	46.0	57.7
Mean	49.6	83.2	56.2	74.3	67.2	77.4
125 lbs. 0–0–20 contact	60.6	89.1	82.3	92.7	85.0	96.0
250 lbs. 0–0–20 contact	48.0	85.7	66.7	90.3	78.7	92.0
375 lbs. 0–0–20 contact	36.9	80.5	53.0	87.3	56.0	83.3
500 lbs. 0–0–20 contact	32.4	71.7	32.7	71.0	30.3	80.0
625 lbs. 0–0–20 contact	24.9	66.3	21.0	68.3	24.0	63.0
750 lbs. 0–0–20 contact	23.6	58.4	16.3	64.0	6.0	41.0
Mean	37.7	75.3	45.3	78.9	46.7	75.9
125 lbs. 0–20–20 contact	53.4	89.9	57.3	86.3	79.7	88.0
250 lbs. 0–20–20 contact	33.3	77.5	33.0	72.3	37.0	74.0
375 lbs. 0–20–20 contact	26.0	63.2	23.0	58.7	20.7	52.0
500 lbs. 0–20–20 contact	24.6	55.6	6.0	52.3	13.3	42.7
625 lbs. 0–20–20 contact	15.2	47.4	3.3	37.7	5.3	25.7
750 lbs. 0–20–20 contact	16.9	43.5	2.3	34.0	6.3	20.3
Mean	28.2	62.9	20.8	56.9	27.1	50.5
500 lbs. 0–20–0 bands	69.2	92.3	82.0	92.3	94.3	96.7
750 lbs. 0–20–0 bands	67.0	91.9	78.0	90.3	97.0	90.7
500 lbs. 0–0–20 bands	58.6	90.7	79.7	93.0	93.7	92.3
750 lbs. 0–0–20 bands	57.9	88.1	72.3	90.7	92.0	92.7
500 lbs. 0–20–20 bands	58.6	88.3	85.7	92.3	96.7	96.3
750 lbs. 0–20–20 bands	58.2	84.2	75.7	89.0	92.0	96.0

TABLE 1.—*Concluded.*

Mean percentage emergence for 3-year period, 1939–41

Fertilizer treatments, pounds per acre equivalent‡	Field studies, Brookston soil		Greenhouse studies			
			Brookston soil		Clermont soil	
	Low soil moisture	High soil moisture	15% soil moisture	25% soil moisture	15% soil moisture	20% soil moisture
Difference necessary between treatments for†:						
Significance	15.1	8.6	19.5	15.4	13.6	10.5
High significance	20.4	11.6	26.3	20.8	18.3	14.1

Analysis of Variance†

Source of variation	D.F.	Mean squares					
Among treatments	15	470**	165**	1,133**	251*	1,531**	413**
Among years	2	7,894**	688**	2,597**	1,357**	598**	349**
Error	30	82.16	26.46	137.33	85.73	66.07	39.40

*Significant differences.
**Highly significant differences.
†The percentage differences between treatments and the analysis of variance apply only to unfertilized and 125-, 250-, and 375-pound per acre fertilizer treatments applied in contact with the seed and to all fertilizer treatments applied in bands.
‡The fertilizer treatments are discussed under materials and methods.

pounds per acre of 0–20–20 fertilizer applied in contact with the seed at the high moisture level on Brookston soil in either the field or greenhouse.

When applied in bands, no fertilizer treatments used significantly reduced emergence below that of the unfertilized plots. Usually the 500-pound per acre treatments applied in bands gave a higher percentage of emergence than the 700-pound per acre band treatments, but the differences between these rates have been relatively small. As with the contact treatments, phosphate alone usually has shown less deleterious effects than potash alone, but the cumulative effects of these elements in the 0–20–20 fertilizer treatments have been nil or almost negligible in the band applications.

When fertilizer was applied in contact with the seed, emergence was almost always less with the lower than with the higher soil moisture level, and there was also a greater reduction in emergence with the lower moisture levels, in comparison to the unfertilized plots than with the higher moisture levels. Except under field conditions, there was little difference in percentage emergence between soil moisture levels on unfertilized plots and in some cases with band fertilizer treatments.

For the average of the three years, 1939 to 1941, the percentage emergence was, in general, higher on Clermont soil than on Brookston soil in the greenhouse studies. The exceptions to this statement which are evident in the 3-year averages and which occurred frequently within the individual years do not warrant concluding that the soil types worked with have a definite influence on soybean emergence with either the presence or absence of fertilizers.

A 3-year summary of the influence of fertilizer treatments on the rapidity of emergence of soybeans grown on Brookston soil in the field at a high moisture content is presented in Fig. 4. This shows that at a high moisture level the fertilizers used delayed emergence in comparison to the untreated plots irrespective of the method of application. Phosphate applied alone delayed emergence less than potash applied alone, and in combination these elements usually delayed emergence for a longer period. Emergence was more rapid when comparable quantities of fertilizers were applied in bands than when applied in contact with the seed.

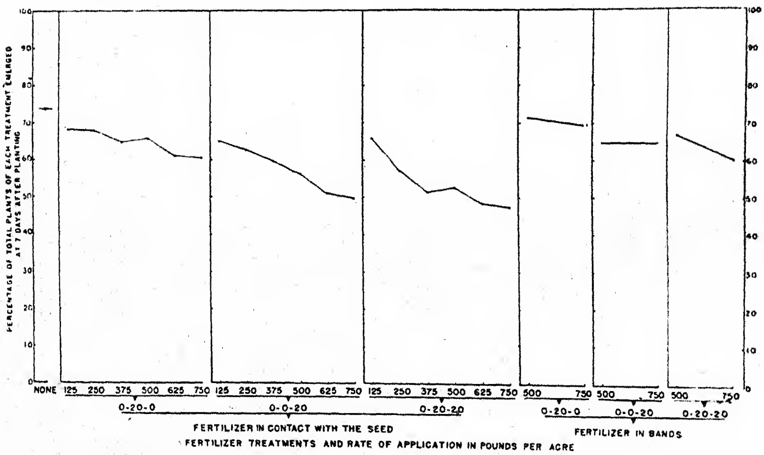


FIG. 4.—The influence of fertilizer and placement treatments on the rapidity of emergence of soybean seedlings on Brookston silty clay loam with a high soil moisture content in field studies. Each percentage point is a mean of three years' data, 1939–41.

As shown by the analysis of variance of the 3-year data, there has been considerable variation in emergence among years, but quite similar comparative emergence has been evident in each of the individual years with the various treatments.

SUMMARY

Studies are reported on the influence of kind and rate of application of fertilizers, fertilizer placement, soil moisture content, and soil type on the emergence of soybeans.

Three analyses of fertilizers applied at six different rates, two methods of placement, two soil moisture levels, and two soil types

were used in these studies during the 3-year period of 1939-41, inclusive. Field studies were made on Brookston silty clay loam, and greenhouse studies on Clermont silt loam and Brookston soil. The Dunfield variety of soybeans was used.

Fertilizers applied to soybeans under the conditions of these experiments usually inhibited emergence to some extent, but not always significantly, irrespective of kind or amount of fertilizer used, placement, soil type, or moisture content of the soil.

In general, emergence was inhibited in proportion to the rate of application and kind of fertilizer used when applied in contact with the seed.

Applications as large as 375 pounds per acre of 0–20–0 or 0–0–20 or of 125 pounds per acre of 0–20–20 did not significantly reduce emergence in these experiments when applied in contact with the seed on Brookston soil with a high moisture level at the time of planting in either the field or greenhouse.

With a low soil moisture content at time of planting, 125 pounds per acre of 0–20–0 or 0–0–20 fertilizer in contact with the seed did not significantly reduce emergence.

When applied in bands to the side of and on the same level as the seed, heavy applications of fertilizer, 500 and 750 pounds per acre of 0–20–0, 0–0–20, or 0–20–20, did not significantly reduce emergence compared with unfertilized plots.

Fewer plants emerged at the low soil moisture content than at the high soil moisture content when the fertilizer was applied in contact with the seed. In the absence of fertilizer, or when the fertilizer was applied in bands, the difference in emergence due to soil moisture content was not so pronounced except under field conditions.

The type of soil used did not appear to have a definite influence on soybean emergence, either in the presence or absence of fertilizers.

Soybeans emerged more rapidly in the absence of fertilizer or in the presence of fertilizer applied in bands than when the fertilizer was applied in contact with the seed.

Phosphate fertilizer delayed emergence less and reduced final emergence less than potash; in combination these fertilizers gave cumulative deleterious effects on emergence and rapidity of emergence when applied in contact with the seed.

LITERATURE CITED

1. BARNES, E. E. Applying fertilizers directly to soybeans. Ohio Agr. Exp. Sta. Bul. 561. 1936. (See pages 19 and 20.)
2. COE, DANA G. "Ammo-Phos:" Its effects upon seed germination and plant growth. N. J. Agr. Exp. Sta. Bul. 375. 1923.
3. HUTCHESON, T. B., and WOLFE, T. K. The effect of fertilizers on the germination of seeds. Va. Agr. Exp. Sta. Ann. Rpt., 1918–19:33–37. 1919.
4. ———, ———. The effect of fertilizers on the germination and bacterial development of inoculated soybean seed. Jour. Amer. Soc. Agron., 14:284–286. 1922.
5. PARKER, M. M., and OLIVER, R. C. The effect of fertilizer placement, as influenced by soil moisture, on seed germination. Amer. Soc. Hort. Sci. Proc., 36:533–536. 1938.
6. SAYRE, CHARLES B., and CLARK, ARTHUR W. Rates of solution and movement of different fertilizers in the soil and the effects of the fertilizers on the ger-

mination and root development of beans. N. Y. State Agr. Exp. Sta. Tech. Bul. 231. 1935.
7. SHERWIN, M. E. The effect of fertilizers on germination and seedling growth. Jour. Amer. Soc. Agron., 15:66–73. 1923.
8. WALKER, G. P., and MULVEY, R. R. Yield of soybeans not affected by fertilizer applied directly with the seed in 1940. Purdue Agr. Exp. Sta. Ann. Rpt., 54:40 and 41. 1941.

EFFECTIVENESS OF RENOVATION IN INCREASING YIELDS OF PERMANENT PASTURES IN SOUTHERN WISCONSIN[1]

H. L. AHLGREN, M. L. WALL, R. J. MUCKENHIRN, AND F. V. BURCALOW[2]

THERE has been a notable and significant decline in the productivity of permanent pastures in Wisconsin during the past 30 years. The cumulative effects of diminishing fertility and early and close grazing have been manifested not only in decreased productivity, but in thinning turf, weed encroachment, and extensive injury by the larvae (white grub) of the June beetle, *Phyllophaga sp.*

The initial research leading to the practical procedure now in effect for establishing legumes in permanent pastures without plowing was begun by Graber (5)[3] in 1925 and reported in 1927. The plan originally visualized the possible extensive use of biennial white blossom sweet clover, *melilotus alba*, in pasture improvement. Heavy seedings of scarified and inoculated sweet clover were made on the surface of frozen ground during late winter and early spring when frequent freezing and thawing occurred. Competition from the grass was reduced and soil contacts for the seed were provided at first by previous burning of the old grass residues or by overgrazing. These and subsequent studies by Graber (6, 7) served as the basis for the development of the plan which is now commonly used in improving the productivity of permanent pastures on hilly, erodable land in Wisconsin.

The procedure which is known as pasture renovation is based on the establishment and maintenance of the heat- and drought-tolerant legumes, sweet clover, *melitotus alba* and *M. officinalis*, alfalfa, *Medicago sativa*, and red clover, *Trifolium pratense*, in the sod of permanent pastures without plowing. The establishment of these legumes is promoted by the restoration of needed fertility and by the preparation of a seedbed by scarification with a disc, spring tooth harrow, or field cultivator. Such tillage serves to retard effectively but not entirely to eliminate the grass component of the sward. In contrast to plowing, scarification with a disc, spring tooth, or field cultivator permits the roots to bind the soil together and this with the broken sods which remain on the surface is very effective in reducing soil losses by erosion even on steep slopes. A somewhat similar procedure for establishing white clover, *Trifolium repens*, and

[1]Contribution No. 187 from the Department of Agronomy, University of Wisconsin, Madison, Wis. Cooperative investigations of the Wisconsin Agricultural Experiment Station, Madison, Wis., and the Lake States Forest Experiment Station, Saint Paul, Minn. Published by permission of the Directors of the Wisconsin Agricultural Experiment Station and the Lake States Forest Experiment Station. Thanks are due H. F. Scholz, Associate Silviculturist, Lake States Forest Experiment Station, and to Professor L. F. Graber, Agronomy Department, University of Wisconsin, for assistance with the study. Received for publication June 14, 1943.

[2]Associate Professor of Agronomy, Wisconsin Agricultural Experiment Station; Agent, Lake States Forest Experiment Station; and Assistant Professors of Soils and Agronomy, respectively, Wisconsin Agricultural Experiment Station.

[3]Figures in parenthesis refer to "Literature Cited", p. 131.

red clover, *T. pratense*, in hill pastures in Wales was proposed by Stapledon (9) in 1933.

The benefits following the successful establishment of heat- and drought-tolerant legumes in permanent pastures have been reported by Graber (5, 6, 7), Graber and Fluke (8), Fluke, Graber, and Koch (2), Fuelleman and Graber (3, 4), and Burcalow, Smith and Graber (1). It has been shown by these investigators that renovation with deep-rooted legumes results in (a) marked increases in productivity, (b) effective reduction of injury by white grubs, and (c) greatly reduced weed growth following the first year.

The present study was begun in the early spring of 1940 to measure (a) the productivity of improved (renovated) and comparable untreated (non-renovated) pastures, (b) the seasonal distribution of the productivity of such pastures, (c) the management necessary to assure the maintenance and continued survival of the legumes in renovated pastures, and (d) the duration of the effects of renovation. The preliminary results which are reported represent only a portion of the agronomic phases of cooperative investigations in which the Lake States Forest Experiment Station and the Wisconsin Agricultural Experiment Station are determining comparative returns from land utilized for timber production, woods-pasture, and open pasture.

PLAN OF EXPERIMENT

Twelve pastures each 4 to 5 acres in size and located in Richland County, Wis., were selected for this study in the early spring of 1940. The pastures were on land of similar topography, erodability, exposure, and soil type. Six of these pastures were located on slopes of from 15% to 25% and the remaining six were on slopes ranging from 26% to 35%. Three pastures within each slope class were renovated and three were untreated. The 12 pastures were distributed among six farms, two pastures of similar slope, one renovated and one untreated, being located on each farm. All of the pastures were located on Gale loam or fine sandy loam, and most of the soils had a depth of 18 to 36 inches over the underlying shaly or sandy residual substratum. Each pasture was located on a dominantly northern exposure and was fenced so that grazing could be controlled and the number of cow pasture days determined.

A good seedbed was prepared in late April and early May in the areas to be renovated by thoroughly tearing up the sod with a field cultivator, followed by discing and harrowing. Ground limestone was applied at the rate of 2 to 3 tons per acre. Calcium metaphosphate (63% P_2O_5) and muriate of potash (50% K_2O) were applied at the rates of 125 and 150 pounds per acre, respectively. The lime and fertilizers were applied prior to discing. A mixture of 15 pounds of inoculated common biennial sweet clover (½ white blossom and ½ yellow blossom) and 5 pounds of inoculated medium red clover was seeded in early May at the rate of 20 pounds per acre.

Twelve wire cages, ¼ mil-acre in size, distributed at random, were used to sample each of the pastures for dry matter production. The forage beneath each cage was clipped after each grazing period on the renovated pastures and twice during the growing period on the untreated pastures. When clipped, the forage was cut at a height approximately equal to that left by the cattle in the grazed portion of the pastures. The forage was dried and weighed. The cages were moved

to new sample areas taken at random within the pastures immediately following each harvest.

Dairy herds of the farmers cooperating in the study were utilized in grazing the pastures. The grazing management used on the renovated pastures was carefully controlled, whereas the untreated pastures were grazed closely and continuously and in a manner approximating that which is usually followed in the region.

MANAGEMENT OF RENOVATED PASTURES DURING YEAR OF ESTABLISHMENT[4]

Although it is a common practice to graze well-established new seedings during the summer months, none of the renovated pastures in this trial was grazed during the first year (1940). While moderate summer grazing helps to eliminate the shading of the new seeding by tall growths of weeds and does not reduce the stand seriously as a rule, it did not prove essential in obtaining uniform stands of vigorous leguminous plants in these trials. Grazing should be withheld in September and early October or until growth has been halted or retarded by frost or cold weather. Light grazing following this period will cause little or no damage to the legumes.

MANAGEMENT OF RENOVATED PASTURES DURING SECOND YEAR

Grazing technics were designed to provide a maximum yield of succulent forage as well as to assure the re-establishment of the legumes from seed produced during the 1941 growing period.

The renovated pastures were grazed by dairy cows in early May of 1941. At this time the legumes were 6 to 8 inches tall. The cattle were removed after the upper 2 or 3 inches of top growth had been eaten. The early spring grazing as practiced resulted in (a) a delay in the maturity of the sweet clover and red clover of from 1 to 2 weeks, (b) the production of a fine-stemmed, leafy regrowth, and (c) an abundance of pasturage before the untreated, permanent pastures were ready for grazing in the spring.

A leafy 12- to 20-inch re-growth of sweet clover and red clover prevailed by the first week in June. The pastures were grazed at this time in such a manner that an 8- to 10-inch leafy stubble remained at the completion of the grazing period.

The sweet clover and red clover were not grazed again until the last week in July. Such delayed grazing was necessary to permit abundant blossoming and the production of ample seed for natural reseeding of the pastures. After seed had formed the pastures were grazed closely for the remainder of the growing period. The Kentucky bluegrass was weakened considerably by this treatment and the legume seeds were trampled into the soil by the cattle.

MANAGEMENT OF RENOVATED PASTURES DURING THIRD YEAR

In 1942, a thick stand of legumes resulted from the natural reseeding of the previous year. Grazing of the renovated pastures was begun during the first and second weeks of May in 1942. At this time the grasses and the third year red clover plants which survived the winter were 4 to 6 inches in height. The red clover and sweet clover seedlings were still very small. Many were in the unifoliolate leaf stage and others were germinating. All of the pastures were grazed closely during this period with no observable damage to the young legume seed-

[4]The management procedure which is described refers only to renovated pastures in which sweet clover and medium red clover are used in the seeding mixture.

lings. This close grazing in early spring reduced further the competition of the Kentucky bluegrass and was effective in making for more uniform grazing later in the season.

The Kentucky bluegrass and third year red clover recovered from the first grazing to the extent that a 4- to 5-inch growth had been produced by the middle of June. It was necessary to graze the pasture at this time to reduce the shading of the legume seedlings by the larger plants. Since the young seedlings had made very little growth, the larger plants were grazed heavily until reduced to the level of the seedlings, after which the cattle were removed. Observations which were made would appear to indicate that moderately heavy grazing during this period is preferable to light grazing in a season of ample rainfall, especially where competition from Kentucky bluegrass is excessive.

Kentucky bluegrass is normally dormant during most of July and August in Wisconsin. Because 1942 was a cloudy season with frequent and well-distributed rainfall, the Kentucky bluegrass continued to grow in July and by August 1, a 10- to 12-inch growth of grass and third year red clover had been produced. This growth was grazed moderately in August until a 4- to 5-inch stubble remained, after which the cattle were removed. The renovated pastures were also grazed moderately during the late fall period after growth had been retarded by frost and cool weather. The stands of red clover and sweet clover were good in the renovated pastures in the 26% to 35% slope class and poor to fair in the renovated pastures in the 15% to 25% slope class at the end of the 1942 growing period.

RESULTS AND DISCUSSION

COW PASTURE DAYS

The data which are given in Table 1 show that renovated pastures within the slope classes of 15% to 25% and 26% to 35% each provided 176 cow pasture days per acre in 1941 and 102 and 88 cow pasture days per acre, respectively, in 1942. Untreated pastures within the 15% to 25% and 26% to 35% slope classes provided grazing at the rates of 83 and 35 cow pasture days per acre, respectively, in 1941 and 72 and 60 cow pasture days per acre, respectively, in 1942. The renovated pastures within the 15% to 25% slope class provided

TABLE 1.—*Cow pasture days obtained from renovated and untreated permanent pastures in Richland County, Wis., during 1941 and 1942.*

Slope class	Farm No.	Renovated		Untreated	
		1941	1942	1941	1942
15–25%	1	194	91	102	86
	2	171	116	91	—
	3	163	98	56	58
Av.		176	102	83	72
26–35%	4	203	77	21	43
	5	192	57	57	83
	6	133	129	27	53
Av.		176	88	35	60

2.1 times more grazing per acre in 1941 and 1.4 times more grazing per acre in 1942 than similarly situated untreated pastures. The renovated pastures within the 26% to 35% slope class provided 5 times more grazing in 1941 and 1.5 times more grazing per acre in 1942 than the corresponding untreated pastures. The renovated pastures in the two slope classes provided an average of 2.17 times more grazing per acre in 1941 and 1942 than the untreated pastures. The number of grazing days obtained from the untreated pastures are higher than were warranted on the basis of forage actually available for grazing. The farmers were permitted to manage these areas according to the procedure which is customary or traditional in the region in which the investigations are being conducted. At times the cattle were observed grazing these pastures even though very little forage was available. Cow pasture days obtained during these periods were included in computing the total number of grazing days provided per acre by the untreated pastures.

DRY MATTER PRODUCTION

The data given in Tables 2 and 3 indicate that the yields of dry matter produced by the renovated pastures in 1941 and 1942 were considerably greater than those of the untreated pastures. Renovated pastures within the 15% to 25% and 26% to 35% slope classes produced an average of 5,075 and 5,019 pounds of dry matter per acre, respectively, during 1941 and 3,887 and 3,000 pounds of dry matter per acre, respectively, during 1942. Untreated pastures within the 15% to 25% and 26% to 35% slope classes produced an average of 1,501 and 920 pounds of dry matter per acre, respectively, during 1941 and 2,109 and 1,465 pounds of dry matter per acre, respectively, during 1942. The renovated pastures within the 15% to 25% slope

TABLE 2.—*Yields of dry matter in pounds per acre from renovated and untreated permanent pastures in Richland County, Wis., during 1941.*

Slope class	Farm No.	Grazing period									
		Renovated					Untreated				
		May	June	July-Aug.	Sept.-Oct.	Total	May	June	July-Aug.	Sept.-Oct.	Total
15–25%	1	907	1,430	2,428	566	5,331	—	550	—	656	1,206
	2	1,177	1,416	1,994	275	4,862	—	1,157	—	533	1,690
	3	1,120	1,649	1,859	404	5,032	—	1,298	—	308	1,606
Av.......						5,075					1,501
26–35%	4	1,521	1,858	1,406	349	5,134	—	750	—	129	879
	5	1,255	1,450	1,649	336	4,690	—	469	—	544	1,013
	6	405	2,034	2,219	576	5,234	—	742	—	127	869
Av.......						5,019					920

TABLE 3.—*Yields of dry matter in pounds per acre from renovated and untreated permanent pastures in Richland County, Wis., during 1942.*

Slope class	Farm No.	Grazing period									
		Renovated					Untreated				
		May	June	July-Aug.	Sept.-Oct.	Total	May	June	July-Aug.	Sept.-Oct.	Total
15–25%	1	1,138	812	1,089	1,652	4,691	—	1,230	—	743	1,973
	2	1,005	567	796	919	3,287	—	1,473	—	494	1,967
	3	704	919	1,063	996	3,682	—	1,836	—	550	2,386
Av.......						3,887					2,109
26–35%	4	938	491	906	752	3,087	—	604	—	411	1,015
	5	307	685	687	550	2,229	—	959	—	519	1,478
	6	748	893	1,273	770	3,684	—	1,320	—	583	1,903
Av.......						3,000					1,465

class produced 3.38 times as much dry matter per acre in 1941 and 1.84 times as much dry matter in 1942 as the untreated pastures within the same slope class. The renovated pastures within the 26% to 35% slope class produced 5.46 times as much dry matter per acre in 1941 and 2.05 times as much dry matter per acre in 1942 as similarly situated untreated pastures. The renovated pastures within the two slope classes provided an average of 2.84 times as much dry matter per acre in 1941 and 1942 as the untreated pastures. The data indicate that significant increases in yield were obtained from the renovated pastures in both slope classes.

The data given in Tables 2 and 3 show that the production of the renovated pastures was more uniformly distributed throughout the growing period than that of the untreated pastures. During 1941, and on the basis of harvested yields, an average of 21.1% of the total seasonal production of the renovated pastures was available for grazing in May, 32.5% in June, 38.1% in July and August, and 8.3% in September and October. Likewise, in 1942 an average of 23.4% of the total seasonal production of the renovated pastures was available for grazing in May, 21.1% in June, 28.1% in July and August, and 27.3% in September and October. Most of the forage available for grazing in the untreated pastures was produced in May and June and in September and October. There was very little forage available for grazing in the untreated pastures in July and August of either 1941 or 1942.

The yields of the renovated pastures were significantly lower in 1942 than in 1941, even though rainfall was more favorable. Lower yields were obtained in 1942 because of (a) a lower utilization of the total production to safeguard the new seedlings of sweet clover and red clover, and (b) the comparatively low yield of forage provided by the seedling sweet clover and red clover plants. It is expected

that with normal seasonal conditions in 1943, the yields of the renovated pastures may be higher than in 1942 because, as in 1941, a large number of plants of sweet clover and medium red clover in their second year of growth will be available for grazing.

BOTANICAL COMPOSITION OF RENOVATED AND UNTREATED PASTURES

The botanical composition of the renovated and untreated pastures is given in Tables 4, 5, and 6. Counts made with a vertical point quadrat in 1941 show that in the renovated pastures 78.1% of the hits (on a frequency basis) were recorded as sweet clover and red clover, whereas 13.9% of the hits were scored by Kentucky bluegrass and 5.5% by redtop. From these data it is evident that the legumes,

TABLE 4.—*Botanical composition of the sward of renovated and untreated permanent pastures in Richland County, Wis., during 1941.**

Treatment	Composition, %						
	Farm No. 1	Farm No. 2	Farm No. 3	Farm No. 4	Farm No. 5	Farm No. 6	Av.
			Kentucky bluegrass				
Renovated..	11.6	15.7	8.5	16.5	17.9	12.9	13.9
Untreated	62.0	75.8	73.7	62.1	84.4	23.0	63.5
			Sweet clover				
Renovated	48.2	56.3	61.1	25.8	52.5	58.8	50.5
Untreated	—	—	—	0.3	—	0.3	0.1
			Red clover				
Renovated	31.9	19.0	23.7	45.4	20.9	25.0	27.6
Untreated	0.1	—	—	0.1	0.1	2.4	0.5
			Redtop				
Renovated	6.6	7.5	5.3	10.1	2.9	1.1	5.5
Untreated	21.4	14.0	16.0	16.2	8.5	3.2	13.2
			White clover				
Renovated	—	—	—	—	—	—	—
Untreated	12.8	3.0	3.1	4.4	1.1	4.1	4.9
			Timothy				
Renovated	1.1	1.8	0.7	2.2	3.7	1.4	1.8
Untreated	—	3.1	3.3	3.6	1.7	47.1	9.8
			Alsike clover				
Renovated	—	—	—	—	—	—	—
Untreated	—	—	—	—	14.4	—	2.4
			Weeds				
Renovated	0.6	—	0.7	—	2.1	0.8	0.7
Untreated	4.4	4.0	3.1	13.4	3.1	5.6	5.6

*The analysis was based on counts made with a vertical point quadrat apparatus at the time the forage beneath the wire cages was clipped. The above percentages are based on averages. Counts were made at three places within each caged area on each harvest date.

TABLE 5.—*Botanical composition of the sward of renovated and untreated permanent pastures in Richland County, Wis., during 1942.**

Treatment	Composition, %						
	Farm No. 1	Farm No. 2	Farm No. 3	Farm No. 4	Farm No. 5	Farm No. 6	Av.
			Kentucky bluegrass				
Renovated	40.7	56.0	40.4	47.9	57.5	55.9	49.8
Untreated	39.7	37.1	37.7	67.2	71.6	48.8	50.3
			Sweet clover				
Renovated	5.9	0.9	1.0	3.7	1.1	0.2	2.2
Untreated	—	—	—	—	—	—	—
			Red clover				
Renovated	24.0	22.8	17.8	24.0	25.9	31.1	24.2
Untreated	—	0.2	0.9	0.3	1.0	3.0	0.9
			Redtop				
Renovated	20.9	14.1	24.0	18.6	9.3	5.4	15.4
Untreated	47.7	42.5	38.9	18.6	13.4	8.9	28.3
			White clover				
Renovated	0.6	1.2	9.4	0.4	0.9	4.8	2.9
Untreated	0.6	10.8	13.3	7.0	8.5	7.5	8.0
			Timothy				
Renovated	1.7	1.6	0.6	3.6	1.1	0.7	1.5
Untreated	—	1.4	0.8	1.0	2.7	21.3	4.5
			Weeds				
Renovated	6.2	3.4	6.8	1.8	4.2	1.9	4.0
Untreated	12.0	8.0	8.4	5.9	2.8	10.5	8.0

*The analysis was based on counts made with a vertical point quadrat apparatus at the time the forage beneath the wire cages was clipped. The above percentages are based on averages of the first three grazing periods. Counts were made at three places within each caged area.

particularly sweet clover, dominated all other vegetation during the 1941 growing period. The important species comprising the sward of the untreated pastures in 1941 included Kentucky bluegrass, 63.5%; redtop, 13.2%; timothy, 9.8%; white clover, 4.9%; and weeds, 5.6%.

The data show that the botanical composition of the renovated pastures was materially different in 1942 than in 1941. Kentucky bluegrass and redtop accounted for an average of 49.8% and 15.4%, respectively, of the total number of hits recorded in the renovated pastures during 1942. First and third year red clover (primarily third year) provided 24.2% of the total number of hits. The remaining growth consisted of sweet clover, white clover, timothy, and weeds. The sward of the untreated pastures in 1942 included Kentucky bluegrass, 50.3%; redtop, 28.3%; white clover, 8%; weeds, 8%; timothy, 4.5%; and red clover, 0.9%.

The data given in Table 6 show that weed growth was effectively reduced by renovation. In 1941, an average of 91,800 weeds were

TABLE 6.—*Approximate numbers of weeds per acre present in renovated and untreated permanent pastures in Richland County, Wis., during August of 1941 and 1942.**

Slope class	Farm No.	Renovated		Untreated	
		1941	1942	1941	1942
15–25%	1	87,000	70,000	210,000	334,000
	2	137,000	78,000	114,000	270,000
	3	104,000	34,000	42,000	124,000
Average......		109,300	60,700	122,000	242,700
26–35%	4	171,000	130,000	252,000	430,000
	5	40,000	122,000	155,000	276,000
	6	12,000	18,000	849,000	368,000
Average......		74,300	90,000	418,700	358,000

*A 1/20,000 acre quadrat was used in making the counts. Three counts were made at each of 12 random locations in each pasture. Each figure recorded represents the average of 36 counts. Averages are given in round numbers to the nearest hundred.

present per acre in the renovated pastures and 270,350 per acre in the untreated pastures. In 1942, an average of 75,350 weeds were present per acre in the renovated pastures and 300,350 per acre in the untreated pastures. Weeds present in the renovated pastures were generally so small that their effect on production was of little significance.

NUMBER OF WHITE GRUBS PRESENT IN RENOVATED AND UNTREATED PASTURES

The marked effect of renovation on the population of white grubs is indicated in the data given in Table 7. White grub counts were

TABLE 7.—*Approximate numbers of white grubs per acre in renovated and untreated permanent pastures in Richland County, Wis., during 1941 and 1942.**

Slope class	Farm No.	Renovated		Untreated	
		1941	1942	1941	1942
15–25%	1	28,000	22,000	180,000	82,000
	2	52,000	12,000	146,000	84,000
	3	16,000	22,000	248,000	106,000
Average......		32,000	18,700	191,300	90,700
26–35%	4	46,000	20,000	80,000	28,000
	5	64,000	48,000	70,000	58,000
	6	66,000	66,000	202,000	82,000
Average......		58,700	44,700	117,300	56,000

*One count was made at 12 random locations in each field with a 1/20,000 acre quadrat. Each figure recorded represents the average of 12 counts. Averages are given in round numbers to the nearest hundred.

made in the renovated and untreated pastures in late August of 1941 and 1942. The data show that renovation is very effective in reducing the population of white grubs in permanent pastures. An average of 45,350 white grubs was present per acre in the renovated pastures in 1941 and 31,700 per acre in 1942. An average of 154,300 white grubs was present per acre in the untreated pastures in 1941 and 73,350 in 1942.

There was no evidence of white grub injury to the turf of the renovated pastures in either 1941 or 1942, but considerable damage was evident in the untreated pastures in 1941. The relatively low yields and high weed contents of the untreated pastures are no doubt associated, in part at least, with injury caused by white grubs.

SUMMARY AND CONCLUSIONS

Studies were initiated in Richland County, Wis., in the spring of 1940 to obtain exact information relative to (a) the productivity of renovated and untreated pastures, (b) the seasonal distribution of the productivity of renovated and untreated pastures, (c) the management necessary to assure the maintenance and continued survival of the legumes in renovated pastures, and (d) the duration of the effects of renovation.

Each of the 12 pastures selected for the study was 4 to 5 acres in size. All were similar with respect to topography, erodability, exposure, and soil type. Six of the pastures were located on slopes of from 15% to 25% and the remaining six were on slopes ranging from 26% to 35%. Three of the pastures within each slope group were renovated and three were untreated.

Managerial technics used in grazing the renovated pastures in 1940, 1941, and 1942 are described. The grazing management was designed to obtain maximum utilization of the available forage while assuring the extablishment, maintenance, and re-establishment of the sweet clover and red clover.

Renovated pastures within the slope classes of 15% to 25% and 26% to 35% each provided 176 cow pasture days per acre in 1941 and 102 and 88 cow pasture days per acre, respectively, in 1942. Untreated pastures within the 15% to 25% and 26% to 35% slope classes provided grazing at the rates of 83 and 35 cow pasture days per acre, respectively, in 1941 and 72 and 60 cow pasture days per acre, respectively, in 1942.

Renovated pastures within the 15% to 25% and 26% to 35% slope classes produced an average of 5,075 and 5,019 pounds of dry matter per acre, respectively, in 1941, and 3,887 and 3,000 pounds of dry matter per acre, respectively, in 1942. Untreated pastures within the 15% to 25% and 26% to 35% slope classes produced an average of 1,501 and 920 pounds of dry matter per acre, respectively, during 1941 and 2,109 and 1,465 pounds of dry matter per acre, respectively, in 1942.

The production from the renovated pastures was more uniformly distributed throughout the growing period than that of the unimproved pastures.

The legumes, particularly sweet clover, dominated all other vegetation in the renovated pastures in 1941. The dominant vegetation in the renovated pastures in 1942 was Kentucky bluegrass, red clover, and redtop. Kentucky bluegrass and redtop provided an average of only 19.4% of the total number of hits (on a frequency basis) in the renovated pastures in 1941. During 1942 65.2% of the total number of hits were recorded as Kentucky bluegrass and redtop.

Weed growth and white grubs were effectively reduced by renovation. In the six renovated pastures the number of weeds was 66.1% less in 1941 and 74.9% less in 1942 than in the untreated pastures. Likewise, in the six renovated pastures the white grub population was 70.6% lower in 1941 and 56.8% lower in 1942.

LITERATURE CITED

1. BURCALOW, F. V., SMITH, D. W., and GRABER, L. F. The duration of the effects of renovation in the control of weeds and white grubs in permanent pastures. Jour. Amer. Soc. Agron., 32:15–22. 1940.
2. FLUKE, C. L., GRABER, L. F., and KOCH, KARL. White grubs. Wis. Agr. Exp. Sta. Bul. 425:88–93. 1933.
3. FUELLEMAN, R. F., and GRABER, L. F. Pasture renovation in relation to populations of white grubs. Jour. Amer. Soc. Agron., 29:186–196. 1937.
4. ————, ————. Renovation and its effect on the population of weeds in pastures. Jour. Amer. Soc. Agron., 30:616–623. 1938.
5. GRABER, L. F. Improvement of permanent bluegrass pastures with sweetclover. Jour. Amer. Soc. Agron., 19:994–1006. 1927.
6. ————. Evidence and observations on establishing sweetclover in permanent bluegrass pastures. Jour. Amer. Soc. Agron., 20:1197–1208. 1928.
7. ————. Renovating bluegrass pastures. Wis. Agr. Exp. Sta. Circ. 277. 1936.
8. ———— and FLUKE, C. L. White grub damage can be prevented and repaired. Wis. College of Agr. Spec. Circ. Jan. 1934.
9. STAPLEDON, R. G. An account of the organization and work of the station from its foundation in April 1919 to July 1933. 143–155. 1933.

THE EFFECT OF SOME ENVIRONMENTAL INFLUENCES IN BULK HYBRIDIZATION OF GRASS[1]

JOHN W. CLARK[2]

THE smallness of the floral parts of some grasses makes the work of controlled hybridization tedious and slow. A simple, inexpensive, and accurate method for bulk hybridization would be useful and would speed up the work. The investigation herein reported was designed to study further the possibility of bulk hybridization. The technic involves immersion of inflorescences in water heated to specific temperatures to effect inactivation of pollen. As a necessary corollary, the desired pollen is then applied by any of several methods.

It is now well known that controlled heat treatments applied to inflorescences near the time of anthesis are effective in seriously reducing the viability of pollen without having a similar effect on the female gametophyte. However, good female fertility has not been found following complete male sterilization. It has become apparent that influences of the plants' environment other than the heat of the emasculation treatment must be taken into consideration.

The present study was conducted on three important forage grasses, namely, smooth bromegrass, *Bromus inermis* Leyss., crested wheatgrass, *Agropyron cristatum* (L.) Goertn., and western wheatgrass, *Agropyron smithii* Rydb. The general findings of earlier investigators are substantiated, and, in addition, evidence is presented to show the existence of a daily cycle in the efficiency of emasculation of treatments at critical temperatures.

REVIEW OF LITERATURE

The literature on bulk emasculation and bulk pollination has been adequately reviewed by Domingo (2)[3] and will be mentioned only briefly here. Stephens and Quinby (4) reported the effectiveness of hot water in the emasculation of sorghum. Jodon (3) reported that both hot and cold water were effective in the emasculation of rice. Suneson (5) demonstrated that wheat was partially emasculated by prolonged low air temperatures. Bulk pollen transfer has long been useful in corn breeding, as indicated by Webber (6), in 1900, and Coulter (1), in 1919. It has also been effective in obtaining hybrids among other cereals, as reported by several investigators.

Perhaps the most critical and extensive study reported in the literature covering both bulk emasculation and pollination is that of Domingo (2). He attempted

---

[1]Contribution from the Department of Agronomy, Utah Agricultural Experiment Station, Logan, Utah, and the Division of Forage Crops and Diseases, Bureau of Plant Industry, Soils and Agricultural Engineering, Agricultural Research Administration, U. S. Dept. of Agriculture. A thesis submitted to the graduate school of Utah State Agricultural College in partial fulfillment of requirements for the degree of master of science. Authorized for publication by the director, Utah Agricultural Experiment Station, September 1, 1942. Received for publication June 22, 1943.

[2]Research fellow in Agronomy, formerly agent, Division of Forage Crops and Diseases. The author wishes to express his appreciation to Dr. Wesley Keller, Associate Geneticist, Division of Forage Crops and Diseases, for helpful suggestions during the course of this investigation.

[3]Numbers in parenthesis refer to "Literature Cited", p. 140.

bulk emasculation of smooth bromegrass by the use of hot water, hot air, and cold air. The plants used were selected on the basis of their relatively high self-fertility. The success of emasculation was measured by the difference in seed set of treated panicles which were selfed and those which were exposed to atmospheric pollen. Hot water treatments were made for 5 minutes at 1° intervals from 37° to 51° C by immersing the panicles in water contained in a 1-gallon thermos jug. Several treatments prevented the formation of selfed seed yet permitted the formation of seeds on similarly treated panicles which were exposed to atmospheric pollen, but the results were not altogether consistent. The most effective temperatures appeared to be 46° and 47° C. Hot air was found to be effective in emasculating smooth bromegrass, but the results were less consistent than with hot water. Several methods of bulk pollination tried by Domingo all yielded some hybrid seed. However, in a preliminary study conducted on the bulk pollination of emasculated panicles, little seed was produced.

EXPERIMENTAL METHODS

Bulk emasculation and bulk pollination were attempted on three species of grasses by treating the inflorescences with hot water at specific temperatures 1 to 3 days prior to anthesis. During anthesis, pollen was transferred from male to female parents by several different methods listed below. To insure against damage to the culms when inserting the inflorescences into the thermos jug, a large handkerchief was wrapped firmly around the group to be treated, starting at the base and extending upward. Plants were selected for treatment which had previously produced considerable selfed seed when isolated in kraft bags. The success of the technic was evaluated by a difference in the amount of seed produced following hot water treatments and specific pollination practices relative to seed produced by controls. Several inflorescences were treated simultaneously and bagged immediately, or left exposed, according to the methods which follow:

1. Selfed.
2. Bagged, but having strained pollen introduced into the bag on 5 days favorable for atmospheric pollination.
3. Bagged, but having severed pollen-bearing inflorescences introduced into the bag on 5 successive days favorable for atmospheric pollination.
4. Bagged, with severed pollen-bearing inflorescences standing in water and inserted into the bag at the beginning of anthesis.
5. Bagged, but in association with intact inflorescences of another genotype (untreated) that provided pollen.
6. Bagged, but exposed 1 hour on each of 5 successive days favorable for atmospheric pollination.
7. Bagged without treatment, then being subjected to various numbers of daily exposures at hourly intervals on days favorable for atmospheric pollination.
8. Exposed to natural pollination following emasculation treatment.
9. Untreated and unbagged. Three inflorescences from each of the several genotypes were harvested and seed counts obtained. This gave a check on the efficiency of the various methods of controlled pollination.

Of the three species experimented with, methods 4 and 7 were not applied to smooth bromegrass; methods 5, 6, and 7 were not applied to crested wheatgrass, and methods 2 and 5 were not applied to western wheatgrass.

Treatments that effected emasculation without appreciable injury to the female organs were detected by lack of seed set on the selfed inflorescences, accompanied

by formation of seed on those which received the same treatment simultaneously but remained exposed to natural pollination. The pollen transfer methods were used to produce controlled hybrids on the inflorescences that had been emasculated. They also served as a check on the viability of the stigmas. Inflorescences not treated and unbagged gave a measure of the effectiveness of atmospheric pollen and apparent injury to the stigmas by treatment with hot water.

Equipment for emasculation.—Emasculation equipment consisted of a wide-mouth thermos jug, an accurate thermometer, and a wire loop for stirring the water in the thermos jug. A one-burner gasoline stove was useful for heating water in the field, and it, together with a water bag filled with cold water, provided a means of making temperature changes rapidly.

Equipment for isolation.—Isolation of spikes or panicles was made possible by the use of 3×26 inch kraft paper bags. The bags were supported by a No. 9 galvanized wire that was forced into the ground at the base of the plant. A 1¾-inch loop in the upper end of the wire prevented the bag from collapsing and thus injuring the inflorescences.

Equipment for pollination.—A large light reflector was used to gather pollen for the isolation bags that were to receive strained pollen. The pollen was separated from the anthers by a fine mesh screen. A small metal container was used to carry the strained pollen from one genotype to another. This container was wrapped with cloth and the cloth soaked in water. Evaporation cooled the container and helped prevent the pollen from forming aggregates. A teaspoon was used to transfer the pollen from the metal container into the isolation bags. In one of the several other bulk pollen transfer methods employed stems were severed near their bases and placed in water contained in 1-quart mason jars, in order to extend the period during which their inflorescences would shed viable pollen. None of the other methods of pollination required equipment.

EXPERIMENTAL RESULTS

DEMONSTRATION OF DIFFERENTIAL AND COMPARISON OF SEVERAL METHODS OF BULK POLLINATION

A differential in the thermal death point of male and female gametophytes is demonstrated if, following an emasculation treatment, self pollen is nonfunctional while untreated introduced pollen leads to seed formation. This relationship is most easily demonstrated with relatively self fertile genotypes. Data supporting the differential for the respective grasses involved are presented in Table 1. The most appropriate critical temperature appears to be 47° C. However, good results were also obtained at 48° C on *A. smithii*. Three relatively self-fertile genotypes of *B. inermis* (mean self fertility in kraft bags was 106 seeds per 100 spikelets) were restricted to 0.1 seed per 100 spikelets when treated at 47° C, for 5 minutes and then bagged. These same three genotypes, on panicles treated simultaneously with those selfed, yielded 10.3 seeds per 100 spikelets when untreated pollen was introduced during anthesis, and 26.8 seeds per 100 spikelets were obtained when the isolation bag was removed for 1 hour during anthesis on each of 5 days favorable for atmospheric pollination.

A similar interpretation is appropriate to *A. cristatum* and *A. smithii*. In no case did the several methods of controlled pollination

differ significantly in effectiveness, but exposure to random natural pollination gave increases in seed over controlled pollination, whereas treated inflorescences which were not bagged at all invariably yielded several times more seed than was obtained from bagged inflorescences. Two important questions are raised here, namely, (a) Are any methods of pollination of bagged inflorescences adequate, including 1-hour exposures on 5 successive pollen shedding days, and if so, (b) are the reduced seed yields under bags an indication that the bag itself has an effect which is additive to that of the emasculation temperature treatment? The limited information at hand does not allow satisfactory answers.

TABLE 1.—*Seeds produced by selfing, intermittent or continuous exposure, and by controlled hybridization procedures, using relatively self-fertile genotypes of B. inermis, Agropyron cristatum, and A. smithii following hot water emasculation treatments at specified temperatures.**

5-minute treatment at °C	*Bromus inermis*† (means of 3 genotypes)				*Agropyron cristatum* (means of 4 genotypes)					*Agropyron smithii* (means of 9 genotypes)				
	1‡	2	6	7	1	3	4	5	7	1	4	5	6	7
48°	—	—	—	—	0	2.3	4.6	0	33.4	1.9	17.6	12.0	28.4	79.0
47°	0.1	10.3	26.8	86.6	0.6	23.2	6.0	12.8	91.6	2.2	11.5	20.0	28.7	91.5
46°	8.2	39.8	56.3	145.0	4.8	17.2	28.0	16.0	132.8	5.5	25.0	23.6	42.0	99.4
45°	17.3	36.5	88.0	206.0	31.6	41.2	15.6	14.8	136.0	14.0	18.8	19.8	33.6	119.9
44°	—	—	—	—	20.8	18.0	42.4	35.6	126.8	26.2	30.9	24.9	39.0	150.6
43°	—	—	—	—	14.0	33.6	34.8	28.0	175.2	24.9	30.0	64.0	62.4	160.2
Untreated	106.0	99.0		288.0	51.6				126.8	30.5				

*None of the controlled hybridization procedures differed significantly in seed production. 47° C appears to be the most suitable emasculation temperature. Each cell in the table is based on 2,150 to 4,160 spikelets for *B. inermis*, 11 to 20 spikes for *A. cristatum*, and 26 to 43 spikes for *A. smithii*.

†Seeds per 100 spikelets. *A. cristatum* and *A. smithii* based on seeds per 4 spikes.

‡Description of procedure following treatment: 1, selfing; 2, plants were grown in pairs, two genotypes bagged together, the one providing pollen was untreated; 3, freshly strained pollen from a different genotype was introduced into bag on 5 successive pollen-shedding days; 4, two severed pollen-bearing spikes suspended in top of isolation bag on each of 5 successive pollen-shedding days; 5, two severed pollen-bearing spikes standing in water, at beginning of anthesis; 6, isolation bag was removed for 1 hour during anthesis on each of 5 pollen-shedding days; 7, inflorescences were continuously exposed (unbagged).

SUCCESSIVE DAILY EXPOSURES

An experiment was conducted with western wheatgrass in order to determine the adequacy for cross pollination of the five daily exposures as reported in Table 1. Different groups of untreated but bagged spikes were exposed to wind pollination for 1 hour on one to four successive pollen-shedding days. In addition, one group was continuously exposed and another remained continuously bagged. From the four groups receiving daily exposures bags were removed in mid-afternoon when pollen shedding was at its height. The plants used were located in a large block of western wheatgrass which was thought to constitute an adequate pollen source. Nine plants were bagged, each contributing one bag of four spikes to each of the six treatments. The results were as follows:

Selfed (continuously bagged)	30.5 seeds
Exposed for 1 hour on 1 pollen-shedding day	49.7 seeds
Exposed for 1 hour on 2 pollen-shedding days	47.5 seeds
Exposed for 1 hour on 3 pollen-shedding days	40.6 seeds
Exposed for 1 hour on 4 pollen-shedding days	73.4 seeds
Continuously exposed (not bagged at all)	140.9 seeds

Most of the daily exposure treatments yielded fewer seeds than were expected. The data are not consistent, since two and three daily exposures failed to yield more seeds than one exposure. Air temperatures during the course of this study were considerably below normal. This is believed to have had a disturbing effect on the progress of pollination and fertilization. These data, therefore, do not allow a clear-cut interpretation.

DAILY TEMPERATURE FLUCTUATIONS INSIDE AND OUTSIDE ISOLATION BAGS DURING ANTHESIS

In recognition of the possibility that high temperatures developed inside the isolation bags, readings were taken simultaneously inside and outside the bags four or 5 times daily.

A small hole was made in the top of each isolation bag just large enough for a thermometer to be inserted. When the temperature was not being taken a small piece of adhesive tape covered the opening. Two accurate thermometers were used, one inside the bag, and the other in the shade of the bag, for recording the atmospheric temperature. Each thermometer was left in position long enough to adjust fully to the temperature encountered. The data are presented in Fig. 1. Each point in the figure is the mean of nine readings, each taken in a different bag.

During the daytime, temperatures within the bags ranged approxmately 2 degrees above those taken simultaneously in the shade of the bags. It is considered unlikely that a difference in temperature of this magnitude would be responsible for the very significant reduction in seeds produced under bags. It is probable, however, that light, humidity, air composition, or other factors which the bag might influence, or a combination of any of these, might contribute to the effect noted. It is also probable that part of this effect relates to inadequate pollination, even when exposures were made for 1 hour during anthesis on each of 5 successive pollen-shedding days.

THE EFFECT OF TIME OF TREATMENT ON SEED PRODUCTION

One genotype of smooth bromegrass was selected to receive treatments at hourly intervals throughout the day from 6:00 a.m. to 6:00 p.m. Treatments were made at 45°, 46°, and 47° C. At each temperature 16 panicles were treated simultaneously and then separated into six groups for pollination by different methods, as follows:

1. Two panicles bagged in association with two intact panicles of another genotype (untreated) which provided pollen.
2. Same as 1 but in addition a cotton plug was placed in the top of each bag to serve as a ventilator.

3. Three panicles bagged and pollinated on 5 successive pollen-shedding days by introducing strained pollen into the top of the isolation bag.
4. Three panicles bagged and pollinated by suspending two panicles in early anthesis in the top of the isolation bag on each of 5 pollen-shedding days.
5. Three panciles were bagged, but the bags were removed for 1 hour during anthesis on each of 5 successive pollen-shedding days.
6. Three panicles left unbagged for natural open pollination.

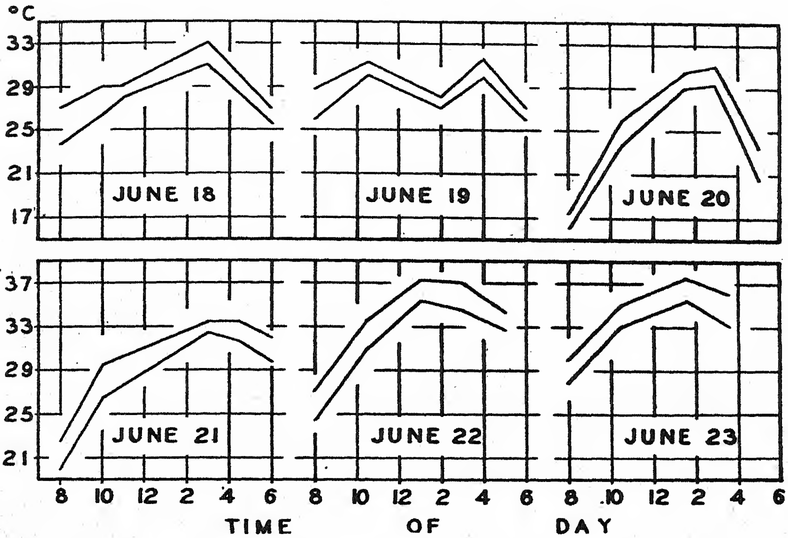


FIG. 1.—Air temperatures inside (upper lines) and outside the isolation bags (lower lines) for a period of 6 days during anthesis. Each bag contained four spikes of *Agropyron cristatum*. Data for *Bromus inermis* (not presented) were essentially identical.

Results from the first five groups, in which bags were involved, are presented in Table 2. The data represent means for the three treatment temperatures. It is evident that seed production is low. The data suggest injury to the stigmas since four of the five methods were approximately equal in efficiency. Examination of the means of different treatment intervals reveals a pronounced daily cycle, many more seeds resulting from the treatments made during the warmer part of the day than during the cooler part.

The data for the sixth method of pollination listed above are presented in Table 3. Approximately half as many seeds were produced by open pollination of panicles treated at 47° C as by those treated at 46° C. Likewise, only half as many seeds were produced following treatment at 46° C as at 45° C. Since the only difference was the treatment temperature, it appears to be a reasonable conclusion that at the higher temperatures an increasing amount of injury was suffered by the stigmas. The means for time of treatment

TABLE 2.—*Effect of time of treatment on seed production by five methods of cross pollination in a self-sterile genotype of smooth bromegrass.**

Treatment	Time of treatment							Mean for each cross pollination method
	a.m.			p.m.				
	6–7	8–9	10–11	12–1	2–3	4–5	6†	
A × B, bagged together...	0.2	0.0	3.3	6.7	3.0	0.0	0.0	1.88
A × B (cotton plug), bagged together...........	0.2	1.0	2.2	2.4	3.1	3.3	0.0	1.76
A, selfed plus pollen 5 days	0.0	2.3	4.4	2.5	3.6	2.6	0.0	2.21
A, selfed plus severed stems 5 days................	0.1	0.1	1.1	0.9	0.4	0.0	0.0	0.38
A, selfed plus 1 hour exposure 5 days.............	0.2	1.0	8.7	0.3	1.3	1.9	0.1	1.93
All methods, 2-hour means	0.14	0.88	3.94	2.56	2.28	1.56	0.02	

*Figures are seeds per 100 spikelets. Means of treatment at 45°, 46°, and 47° C. Each value is an average of 1,351 spikelets, or a total of 43,930 spikelets for the table as a whole.
†Actual values obtained from panicles treated at 6:00 p.m. have been doubled in order to make this column more comparable to the others, which are for two treatments each.

classes point clearly to the daily cycle which characterized the data presented in Table 2 for bagged plants. Thus, it is evident that this cycle is not an effect of the bag. It is also evident that the cycle is most clearly expressed at the higher treatment temperatures.

TABLE 3.—*Seeds produced per 100 spikelets of a self-sterile genotype of smooth bromegrass.**

Treatment, °C	Hour of treatment							Means for each emasculation temperature
	a.m.			p.m.				
	6–7	8–9	10–11	12–1	2–3	4–5	6†	
47°..............	3.6	12.2	0.6	108.0	136.2	25.7	44.5	47.3
46°..............	39.8	10.5	102.2	116.5	105.6	87.7	96.5	79.8
45°..............	138.0	104.2	184.0	170.0	212.5	179.5	114.0	157.5
Mean............	37.3	40.2	95.5	131.2	151.0	93.6	84.8	

*The plants were emasculated at hourly intervals throughout the day but remained unbagged. Treatments were either 45°, 46°, or 47° C for an interval of 5 minutes. Each value is an average of 255 to 271 spikelets, or a total of 7,545 spikelets for the table as a whole.
†Actual values obtained from panicles treated at 6:00 p.m. have been doubled in order to make this column more comparable to the others, which are for two treatments each.

Table 4 presents the data of Table 2 rearranged according to treatment temperatures. The striking feature of these data is the relationship of treatment temperature to the range in time of day through which treatment led to relatively good seed sets. Relatively high seed sets were obtained from treatments at 47° C only when these treatments were made in mid-day (12 noon to 1 p.m.). At 46° C relatively high seed yields were obtained when treatments were

made between 10 a.m. and 3 p.m., while at 45° C the time range of relatively good seed yields was extended from 8 a.m. to 5 p.m. Although the data do not so indicate, it is suspected that emasculation at 45° C may not have been highly effective at mid-day. In a broad sense, these conclusions drawn from Table 4 are borne out by the data presented in Table 3.

TABLE 4.—*Seeds produced per 100 spikelets in a self-sterile genotype of smooth bromegrass by cross pollination following emasculation at hourly intervals throughout the day.**

Treatment, °C	Time of treatment							Means for each emasculation temperature
	a.m.				p.m.			
	6–7	8–9	10–11	12–1	2–3	4–5	6†	
47° treatment, 5 min......	0.1	0.6	0.5	4.0	0.6	0.0	0.0	0.84
46° treatment, 5 min......	0.2	0.2	3.8	1.9	4.1	0.5	0.1	1.47
45° treatment, 5 min......	0.1	1.8	7.5	1.8	2.2	4.2	0.0	2.52
Two-hour means.........	0.13	0.87	3.93	2.57	2.30	1.57	0.03	

*Each value in the table is a mean of five methods of cross pollination. Each value is an average of 2,252 spikelets, or a total of 43,930 spikelets for the table as a whole.

†Actual values obtained from panicles treated at 6:00 p.m. have been doubled in order to make this column more comparable to the others, which are for two treatments each.

DISCUSSION

In the present study all controlled pollination methods were applied to treated inflorescences. The data presented in Table 1 reveal significant increases in seed production, and clearly demonstrate that a differential exists, but that seed production on bagged inflorescences is consistently far below that of similarly treated but unbagged inflorescences. This may be interpreted in either of two ways, (a) all methods of controlled pollination were inefficient, or (b) the bag has an effect which is additive to that of the emasculation treatment. Critical evidence is not at hand, and therefore both possibilities will require further consideration. Smooth bromegrass (Table 1), under relatively normal weather conditions, yielded less than half as many seeds when opportunity for pollination consisted of five daily 1-hour exposures as were obtained when the treated panicles were continuously exposed. It would seem highly improbable that five daily exposures of 1 hour during the height of anthesis would fail to provide ample opportunity for pollination of a large percentage of the flowers. On the contrary, the kraft bag used in this study has been in use at this station for five seasons in self-pollination studies. Many highly self-fertile plants have been detected by its use. The bag alone, therefore, does not appear to sterilize the plants.

Data are presented showing that temperatures within the bags are approximately 2° C higher than those outside the bags. If an increase of 2° in the air temperature would be lethal to pollen, seed production would be impossible during some warm seasons. No such condition is known to exist.

Clear-cut evidence is presented in Tables 2, 3, and 4 to demonstrate the operation of a daily cycle in the reaction of the plant toward the emasculation treatment. It is clear that a given temperature has a more severe effect on the plant in the early morning and late afternoon than at mid-day when the atmospheric temperature most nearly approached that of the treatment.

Although new difficulties have been brought to light, the present study adds weight to the belief that bulk hybridization can be realized because data are presented supporting the basic requirement of the method, namely, the existence of a differential in the thermal death points of male and female gametophytes.

SUMMARY

Evidence is presented supporting the findings of other investigators that there is a differential in the thermal death points of male and female gametophytes. The differential is best demonstrated by hot water treatment at 47° C for 5 minutes just prior to normal anthesis.

Hot water emasculation at temperatures of 45°, 46°, and 47° C at 1-hour intervals from 6 a.m. to 6 p.m. revealed that treatments at mid-day were less injurious to the plant than treatments in the early morning or late afternoon. A treatment of 45° C at 6 a.m. appeared to give as effective an emasculation as a treatment of 47° C at noon.

Five methods of controlled pollination were investigated, but none gave satisfactory seed yields. The low seed yields obtained were the result of some factor or combination of factors other than emasculation treatment, since similarly treated inflorescences exposed to continuous wind pollination (not bagged) gave satisfactory seed yields.

Air temperatures inside the isolation bags were found to be approximately 2° C higher than those outside the bags.

LITERATURE CITED

1. Coulter, Merle C. A corn-pollinator. Bot. Gaz., 68:63–64. 1919.
2. Domingo, Wayne E. Bulk emasculation and pollination of smooth bromegrass, *Bromus inermis*. Jour. Amer. Soc. Agron., 33:993–1002. 1941.
3. Jodon, N. E. Experiments on artificial hybridization of rice. Jour. Amer. Soc. Agron., 30:294–305. 1938.
4. Stephens, J. C., and Quinby, J. R. Bulk emasculation of sorghum flowers. Jour. Amer. Soc. Agron., 25:233–234. 1933.
5. Suneson, Coit A. Emasculation of wheat by chilling. Jour. Amer. Soc. Agron., 29:247–249. 1937.
6. Webber, Herbert J. Xenia, or the immediate effect of pollen, in maize. U.S.D.A. Div. Veg. Phys. and Path. Bul. 22. 1900.

FIELD AND GREENHOUSE TESTS WITH SYNTHETIC GROWTH-REGULATING SUBSTANCES APPLIED TO SUGAR BEET SEEDS AND PLANTS[1]

MYRON STOUT AND BION TOLMAN[2]

CONSIDERABLE publicity has recently been given to the possibility of modifying growth through the application of certain synthetic growth-regulating substances to the seeds or to the foliage of plants. Claims have been made in advertising pamphlets, newspapers, trade journals, radio advertising, and some scientific publications that the application of these chemicals and commercial preparations greatly increased the yield and quality of plants. There have also been a number of reports showing that applications of a large number of these substances at different concentrations to a wide variety of plants have produced no beneficial response. Various methods of applying these substances to plants or seeds have been used. Seeds are usually dusted with flour or talc containing the substance or soaked in dilute aqueous solutions before planting. Growing plants are usually treated with a dust or spray containing the substance. Recent publications (5, 7)[3] have given fairly complete reviews on the broader aspects of the subject. The purpose of the present report is limited to the possible application of some of these substances in sugar beet culture.

Ireland (3, 4) reported tests showing increases in the yields of stock beets and sugar beets amounting to about 200% and 62%, respectively. These yields, however, were estimated and apparently based on non-replicated tests. Amlong and Naundorf (1) reported increased yields up to 157% and slightly reduced sugar percentage when seed was soaked for 24 hours in 1/100 normal heteroauxin (indoleacetic acid). Nuckols (8) reported no significant beneficial results from any of the seed treatments applied at Scotts Bluff, Nebr. Stewart and Hamner (9) also reported no statistically significant response from any of the treatments used on sugar beets planted at Beltsville, Md., or at Lake Geneva, Wis. Replicated tests reported by Dexter (2) failed to show any increase in yield, sucrose percentage, or purity resulting from the use of several chemicals and commercial preparations.

MATERIALS AND METHODS

Improved U. S. 22 sugar beet seed was used in tests conducted in the greenhouse and in the field.

Dusts containing naphthaleneacetic acid, naphthaleneacetamide, indoleacetic acid, indolebutyric acid, and levulinic acid were prepared by dissolving the chemicals in a suitable solvent, then mixing this solution with talc to produce a thick paste. The mixture was stirred occasionally as drying progressed at room

[1]Contribution from Field Laboratory; Division of Sugar Plant Investigations, Bureau of Plant Industry, Soils, and Agricultural Engineering, U. S. Dept. of Agriculture, Salt Lake City, Utah. Received for publication July 9, 1943.

[2]Assistant Physiologist and Associate Agronomist, respectively.

[3]Figures in parenthesis refer to "Literature Cited", p. 146.

temperature. The dried mixture was ground in a mortar and screened several times through a 100-mesh screen. Dilute concentrations of the chemicals in talc were prepared by diluting the more concentrated preparation with talc and mixing thoroughly. The commercial preparations, "Graino" and "Rootone", were used as supplied by the manufacturers. The dusts were applied to the seed at the rate of 20 grams of dust to 2 pounds of seed. There was an excess of dust in all treatments and this was removed by allowing the dusted seed to roll down a short inclined screen.

Naththaleneacetic acid, naphthaleneacetamide, indoleacetic acid, and indolebutyric acid applied to the plants as sprays were first dissolved in a few ml of a suitable solvent and then diluted with water and emulsifier to the stated concentration.

In greenhouse tests chemicals were applied to plants in a lanolin emulsion spray[4] at four periods of growth, *viz.*, March 21, April 6, April 22, and May 9, 1942. The average total fresh weight of the plants on these dates were approximately 6, 12, 20, and 35 grams respectively. Sprays were prepared for field tests using a light summer oil emulsion (No. 270, purchased from a local chemical supply company).

Each test was conducted using a minimum of four replications on plots arranged in randomized block design and the data were analysed by the analysis of variance method.

EXPERIMENTAL RESULTS

GREENHOUSE TESTS WITH DUSTED SEED

Four replicated plots of each of 14 seed dusting treatments were used in test plantings made in greenhouse soil benches February 2, 1942. Each plot consisted of a single row 2½ feet long. The average fresh weight of the plants in each plot was determined at intervals during a period of 3½ months. The average weight was first determined on March 6, 1942, when the beets were thinned to 20 beets per row. On April 18, 1942, alternate beets were pulled and weighed and on May 15, 1942, the remaining 10 plants in each plot were pulled and their average weight determined. By this method it was possible to ascertain, at three stages of development, whether or not any of the treatments had stimulated growth.

Observations of the growing plants failed to disclose any apparent consistent differences. This was true of seedling emergence as well as growth, indicating that the most concentrated applications were below that necessary to cause injury. The data, presented in Table 1, show that none of the treatments significantly affected the fresh weight of plants at any of the stages of development.

GREENHOUSE TESTS WITH CHEMICALS APPLIED IN SPRAY

Untreated seed was planted in soil benches February 3, 1942. The plants were thinned to 20 beets per row March 6, 1942. Five replications of each spraying treatment received applications of spray containing 2 p.p.m. of the chemicals on March 21, April 6, and April 22. One application at 4 p.p.m. concentration was applied May 9, 1942. Alternate plants from each row were pulled and their average fresh

[4]See Journal of Heredity, 30:419. 1939.

weights were determined April 18. Final average fresh weights of the remaining plants were determined May 15, 1942.

TABLE 1.—*Average fresh weight of plants produced from sugar beet seed dusted with chemicals before planting.**

Treatment	Concentration of chemical in dust, %	Av. fresh weight of beets harvested, grams		
		Mar. 6, 1942	Apr. 18, 1942	May 15, 1942
Talc (check)	0.0	0.470	18.6	31.3
Naphthaleneacetic acid	0.1	0.399	17.5	34.7
	0.01	0.415	16.7	32.7
	0.001	0.427	20.5	31.4
Naphthaleneacetamide	0.1	0.452	17.5	39.9
	0.01	0.455	14.4	32.8
	0.001	0.413	18.5	32.3
Indoleacetic acid	0.1	0.410	19.3	37.0
	0.01	0.401	16.8	27.9
	0.001	0.332	13.0	40.2
Indolebutyric acid	0.1	0.383	18.1	31.8
	0.01	0.422	20.3	28.7
	0.001	0.376	21.0	35.1
Levulinic acid	1.0	0.362	16.2	28.4
General mean of all treatments		0.408	17.73	33.09
Standard error of mean		0.043	1.92	3.52
Significant difference (19:1)		NS†	NS	NS
Calculated F value		0.78	1.38	1.29
F value (5% point)		2.00	2.00	2.00

*Greenhouse test of variety Improved U. S. 22 planted February 2, 1942. Soil pH = 7.7.
†NS = F value not significant.

No differences in growth were observed during the test and the data presented in Table 2 show that there were no significant differences between the treatments at either stage of development.

TABLE 2.—*Average fresh weight of plants sprayed with chemicals in a lanolin emulsion spray.**

Treatment	Average fresh weights of beets harvested, grams	
	Apr. 18, 1942	May 15, 1942
Blank spray (check)	20.62	47.42
Naphthaleneacetic acid	20.84	36.66
Naphthaleneacetamide	19.54	44.04
Indoleacetic acid	15.14	36.38
Indolebutyric acid	18.58	36.00
General mean of all treatments	18.94	40.10
Standard error of mean	1.72	4.75
Significant difference (19:1)	NS†	NS
Calculated F value	1.80	1.24
F value (5% point)	3.01	3.01

*Greenhouse test of untreated seed of Improved U. S. 22 planted February 3, 1942. Spray applied at 2 p.p.m. concentration March 21, April 6, and April 22, 1942. Spray applied at 4 p.p.m. concentration May 9, 1942. Soil pH = 7.7. †NS = F value not significant.

FIELD EXPERIMENTS WITH DUSTED SEED

Since greenhouse tests had shown that no apparent injury resulted from treating seed with the highest concentration of chemical in the dusts previously used, lower concentrations were eliminated in the field tests. Four replicated plots of each of eight seed-dusting treatments were included in a field test planted at Granger, Utah, May 11, 1942. Each plot consisted of four rows 70 feet long. There were no apparent differences in growth during the entire growing season. The beets were harvested October 31, 1942. The beets from the two center rows of each plot were weighed for yield data and duplicate 10-beet samples were selected from each plot for chemical analysis and tare calculation. The data in Table 3 show that there were no significant differences in yield of available sugar, tons of beets, sucrose percentage, or apparent purity.

TABLE 3.—*Harvest data from a field test conducted to determine the influence of certain chemicals and commercial preparations applied in dusting treatments to sugar beet seed before planting.**

Treatment	Concentration of chemical in dust, %	Yield per acre, tons		Sucrose, %	Purity, %	Beets per 100 feet of row at harvest
		Available sugar	Beets			
Talc (check)	0.0	3.480	23.89	17.02	85.68	84
Naphthaleneacetic acid	0.1	3.414	25.05	16.08	84.78	83
Naphthaleneacetamide	0.1	3.457	25.12	16.29	84.58	86
Indoleacetic acid	0.1	3.366	24.38	16.21	85.38	86
Indolebutyric acid	0.1	3.573	24.52	16.88	86.24	86
"Rootone"	0.0	3.516	24.91	16.50	85.70	86
Levulinic acid	1.0	3.438	24.01	16.78	85.56	86
"Graino" special S. B.	0.0	3.495	24.55	16.60	85.76	83
General mean of all treatments		3.468	24.55	16.55	85.46	—
Standard error of mean		0.113	0.88	0.35	0.71	—
Significant difference (19:1)		NS†	NS	NS	NS	—
Calculated F value		0.32	0.27	0.94	0.58	—
F value (5% point)		2.49	2.49	2.49	2.49	—

*Improved U. S. 22; planted May 11; harvested October 31, 1942. Test conducted at Granger, Utah. Soil pH = 8.2.
†NS = F value not significant.

FIELD TESTS WITH NAPHTHALENEACETAMIDE APPLIED IN SPRAY TO GROWING BEETS

Interest in this test was stimulated by recently reported experiments (6, 7) with some of the leafy vegetables which had indicated that the application of naphthaleneacetamide to the foliage in the form of a spray resulted in considerable thickening of the leaf blades and also in altering the top:root ratio of plants. These results suggested the possibility that top growth and ripening of sugar beets might be altered by such applications.

As a supplement to the field seed-treatment tests naphthaleneacetamide was applied to the foliage of sugar beets growing in the field during the summer of 1942. Several concentrations of the chemical were applied in an oil emulsion spray on two different dates.

No differences in foliar growth were observed following the applications, and no differences in yield, sucrose percentage, or purity were apparent when the beets were harvested. The data in Table 4 are the result of four replications of each treatment applied to the two center rows of four-row plots 70 feet long. An even heavier drenching of a few beets was tried and there was no discernible change in foliar growth of the plants.

TABLE 4.—*Harvest data from a field test conducted to determine the influence influence of sprays containing naphthaleneacetamide on the growth and ripening of sugar beets.**

Concentration of chemical applied in spray, p.p.m.		Yield per acre, tons		Sucrose, %	Purity, %	Beets per 100 feet of row at harvest
July 12	Sept. 23	Available sugar	Beets			
Check	Check	3.282	26.98	14.50	83.35	89
1	0.0	3.535	27.64	15.15	84.18	89
10	0.0	3.296	26.92	14.45	84.59	93
10	25	3.196	26.13	14.51	83.88	88
0.0	25	3.459	29.30	14.14	83.24	96
General mean of all treatments		3.353	27.40	14.55	83.85	—
Standard error of mean		0.195	1.03	0.36	0.98	
Significant difference (19:1)		NS†	NS	NS	NS	
Calculated F value		0.51	1.34	1.06	0.34	
F value (5% point)		3.26	3.26	3.26	3.26	
Check	Check	3.324	25.32	15.90	82.52	95
0.0	85	3.470	25.41	16.21	84.03	95
General mean of all treatments		3.397	25.37	16.06	83.28	
Standard error of mean		0.120	0.65	0.40	0.82	
Significant difference (19:1)		NS†	NS	NS	NS	
Calculated F value		0.74	0.01	0.30	1.70	
F value (5% point)		10.13	10.13	10.13	10.13	

*Variety U. S. 22; planted May 11; harvested October 31, 1942. Test conducted at Granger, Utah. Soil pH = 8.2.
†NS = F value not significant.

DISCUSSION

Since the report of phenomenal increases in crop yields as a result of hormone treatments was first made (3, 4), extensive tests with these treatments have been conducted in many sections of the country, most of which have yielded negative results. Most of the tests which indicate no response from hormone treatments have been adequately replicated and the statistical significance of the results determined (2, 5, 7, 8, 9). In contrast to this, most of the tests which

report increased yields from chemical seed treatments were not replicated tests and a statistical measure of the significance of the results was therefore not possible (3, 4). The negative results herein reported are in accord with those of Mitchell and Stewart (7), Stewart and Hamner (9), Nuckols (8), Dexter (2), and Kisselbach (5).

It is recognized that the concentration of chemicals used in the tests reported in this paper was not so great as that reported by some other workers (7, 9). However, the range of concentration was as high as that from which stimulative response has been reported (3).

SUMMARY

Synthetic growth-regulating substances were used in dusts applied to sugar beet seed before planting and in sprays to the foliage of growing sugar beet plants in both greenhouse and field tests. The following chemicals and commercial preparations were used either in dusts or sprays: Naphthaleneacetic acid, naphthaleneacetamide, indoleacetic acid, indolebutyric acid, levulinic acid, "Rootone", and "Grain-O Special S. B.". These chemicals were used in concentrations ranging from 10 to 1,000 p.p.m. in the dust treatments and from 2 to 85 p.p.m. in spray treatments.

No significant benefits as to seedling emergence, vegetative growth, sucrose content, purity, or yield of roots per acre were derived from any of the above treatments applied in greenhouse or field tests.

The results here reported do not lend encouragement to the use of chemical growth-stimulating seed treatments on sugar beets grown in this area. (Utah).

LITERATURE CITED

1. Amlong, H. U., and Naundorf, G. Neue Wege der Pflanzenstimulation. Forschungsdienst, 5:292–303. 1938. (Abs. in Facts About Sugar, 35, No. 3:35. 1940.)
2. Dexter, S. T. Preliminary findings on the use of plant hormones as seed treatments for sugar beets. Mich. Agr. Exp. Sta. Quart. Bul. 24:245–248. 1942.
3. Ireland, J. C. Plant growth regulators applied to crop plants. Okla. A. and M. College. Mimeographed Report. 1942.
4. Ireland, J. C. New miracles with field crops performed. Southern Seedsman, 5:9; 36. Feb. 1942.
5. Kisselbach, T. A. Crop response to hormone seed treatments. Jour. Amer. Soc. Agron., 35:321–331. 1943.
6. Kraus, E. J., and Mitchell, J. W. Histological and physiological responses of bean plants to alpha naphthalene acetamide. Bot. Gaz., 101:204–225. 1939.
7. Mitchell, J. W., and Stewart, Wm. S. Comparison of growth responses induced in plants by naphthalene acetamide and naphthalene acetic acid. Bot. Gaz., 101:410–427. 1939.
8. Nuckols, S. B. Plant hormone treatment of sugar beet seed. Sugar, 37, No. 9:22–23. 1942.
9. Stewart, Wm. S., and Hamner, Chas. L. Treatment of seeds with synthetic growth-regulating substances. Bot. Gaz., 104:338–347. 1942.

THE PLANT BUGS, *MIRIS DOLOBRATUS* L., AND *AMBLYTYLUS NASUTUS* KIRSCHBAUM, AND THEIR INJURY TO KENTUCKY BLUEGRASS, *POA PRATENSIS* LINN.[1]

H. H. JEWETT AND J. T. SPENCER[2]

MIRIS DOLOBRATUS L.

THE meadow plant bug, *Miris dolobratus* L., was first collected in Kentucky in 1908, but it was not until 1924 that it appeared in numbers sufficient to attract attention of seed producers and dealers. Since 1924, there have been years of abundance and scarcity of this plant bug, but during the last four or five years it has been present and destructive in many fields of bluegrass in central Kentucky. The growers, generally, associate light seed crops with damage done by *M. dolobratus*, especially during years of unfavorable weather conditions. To determine the importance, if any, of this insect as a factor in bluegrass seed production, a study was begun in the spring of 1942, attention being directed to host plant identification and the effects of feeding injury on bluegrass seed production.

Garman (2)[3] stated that there was no evidence that the insect attacks anything but bluegrass and that in Kentucky most of the eggs are placed in bluegrass stems.

Osborn (3) stated that in Maine the insect has not been observed commonly on bluegrass or other small grasses or grasses with small seed heads, except as they are mixed with coarser forms and that it feeds primarily on timothy.

The senior author has observed nymphs feeding on Kentucky bluegrass, *Poa pratensis*, Linn., orchard grass, *Dactylis glomerata*, Linn., redtop, *Agrostis alba*. var. *vulgaris*, Thurb., and hairy chess, *Bromus commutatus*, Schrad, where they were all found growing in the same fields. The adults deposited eggs in the stems of these grasses and preferred *B. commutatus* (Table 1). A knowledge of the location of the eggs in the stems is a matter of importance in devising control measures and since the eggs remain in the stems from midsummer until the next spring, control could most likely be effected by attacking the insect in the egg stage.

The insect feeds by piercing with its beak the tissues of plants and sucking the fluids. The blades, stems, and florets of grasses are attacked, and feeding on the florets (Fig. 1) may injure or destroy the ovary, thus preventing seed development. Severe infestation in a dry season causes more noticeable injury than in a normal season, the plants making less growth and the stems being somewhat shorter and the seed heads smaller and less compact. "White heads" are very seldom seen in fields of Kentucky bluegrass in Kentucky even when

---

[1]The investigation reported in this paper is in connection with a project of the Kentucky Agricultural Experiment Station and is published by permission of the Director. Received for publication August 14, 1943.

[2]Research Assistant Entomologist and Assistant Agronomist, respectively.

[3]Figures in parenthesis refer to "Literature Cited", p. 151.

TABLE 1.—*Location of eggs of Miris dolobratus in stems of grass taken from two fields where infestations differed, Fayette County, Ky., 1942.*

Host	Field No.	No. of stems examined	Distance of eggs from soil, in.		Stems infested, %
			Average	Range	
Hairy chess, *Bromus commutatus*	1	200	3.4	1.5 to 6	12.5
	2	100	3.1	0.75 to 10.5	62.0
Bluegrass, *Poa pratensis*	1	200	2.1	1 to 3	7.5
	2	100	3.5	1.25 to 6	26.0
Timothy, *Phleum pratense*	1	200	3.3	1 to 4.5	2.5
	2	100	5.4	1.75 to 11	9.0
Orchard grass, *Dactylis glomerata*	1	200	16.7	2 to 36	7.0
	2	100	14.8	3.25 to 31	25.0
Redtop, *Agrostis alba*	1	200	2.7	2.25 to 3.25	3.0

Miris dolobratus is very abundant. This condition of the seed heads was very noticeable among grasses in Wisconsin (1) when *M. dolobratus* was abundant. Experimental data obtained in 1942 (Table 2) show that the meadow plant bug, when abundant, can prevent practically all seed production.

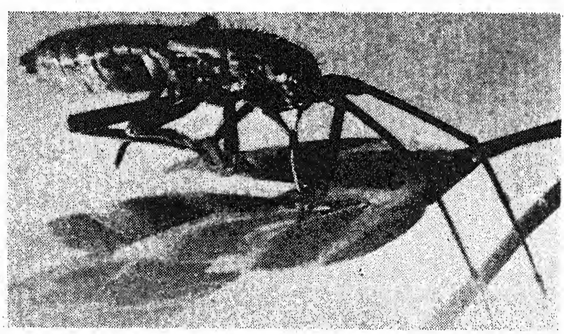


FIG. 1.—Nymph of *Miris dolobratus* feeding on floret of bluegrass, *Poa pratensis*.

AMBLYTYLUS NASUTUS KIRSCHBAUM[4]

This plant bug very probably came into Kentucky within the last few years since it was collected there for the first time in May 1937 by Dr. Lee Townsend of the University of Kentucky. It came into the United States from Europe and has been found in Massachusetts, Indiana, and Michigan.

Very little is known of the life history of the insect. In central Kentucky, newly hatched nymphs appear on bluegrass about the

[4]Determined by Dr. R. I. Sailer.

middle of April at the same time as nymphs of *Miris dolobratus*. In some fields, *Amblytylus nasutus* was much more numerous than the meadow plant bug. *Amblytylus nasutus* feeds on bluegrass seed heads and can prevent seed development (Table 3).

EXPERIMENTAL PROCEDURE

Just as heads of Kentucky bluegrass began to appear in 1942, cages were placed in old stands of grass where it appeared that infestation by mirids would be severe. Fields were selected near Lexington, Winchester, and Paris, Ky. In the tables "A" represents the field at Lexington; "B", the field near Winchester; and "C", the field near Paris. The numbers following the letters are cage or test numbers. The cages were 2 feet square and 2½ feet tall, and the frames were covered with cheesecloth and close-meshed wire screen. The grass was treated with an insecticide several times to kill any insects in the cages and later nymphs of the mirids were placed in half the cages. The nymphs of *Miris dolobratus* were placed in the cages on April 30 and the nymphs of *Amblytylus nasutus* on May 11. Only one species was used in a cage.

Several samples of seed heads taken from infested and uninfested bluegrass in the cages were examined for floret and seed types. Each sample consisted of five spikelets from different locations on each of 20 seed heads. Floret and seed types were classified in the manner directed by Spencer and Fergus (4) in which the following eight types of florets and seed were recognized: A, florets, ovary and stamens present but no pollen; B, florets, pistil and stamens present and anthers containing pollen; C, florets, only a pistil within the floret; D, seed partially developed; E, seeds, partially or completely shriveled; F, seeds, endosperm entirely soft; G, seeds, endosperm partly soft and partly hard; H, seeds, endosperm entirely hard.

TABLE 2.—*Comparison of floret and seed types of Kentucky bluegrass from seed heads infested and uninfested by Miris dolobratus.*

Test No.	Treatment	Floret and seed types: Undeveloped florets			Shriveled seed		Developed seed			Undeveloped florets, %	Shriveled seed, %	Developed seed, %
		A	B	C	D	E	F	G	H			
A 2	Infested	115	53	35	10	5	0	0	0	93.1	6.9	0.0
A 3	Uninfested	9	14	8	15	18	28	40	112	12.7	13.5	73.8
A 4	Infested	68	121	45	19	10	0	0	2	88.3	10.9	0.8
A 5	Uninfested	1	9	11	23	35	23	43	122	7.9	21.7	70.4
A 6	Infested	126	139	36	0	0	0	0	0	99.4	0.6	0.0
A 7	Uninfested	4	14	8	19	53	40	34	115	9.1	25.1	65.8
A 8	Infested	137	20	15	8	2	0	1	3	92.5	5.4	2.1
A 9	Uninfested	9	10	1	4	28	30	34	131	8.1	13.0	78.9
B 21	Infested	136	56	16	30	3	0	0	2	86.0	13.2	0.8
B 20	Uninfested	5	1	40	24	7	16	20	90	22.7	15.3	62.0
C 14	Infested	39	61	12	38	72	15	2	14	44.3	43.5	12.2
C 15	Uninfested	28	6	2	29	47	28	14	96	14.4	30.4	55.2
C 16	Infested	48	161	5	13	23	12	0	0	81.7	13.7	4.6
C 17	Uninfested	31	24	2	16	34	39	12	78	25.1	20.9	54.0

Several heads from some samples were rubbed out on 18-mesh wire screen, and the seed and chaff placed in a standard blower with the air blast adjusted for Kentucky bluegrass. Samples of the resulting seed and light weight seed in the chaff were tested for germination by the Experiment Station Seed Laboratory. Data obtained from these operations are presented in Table 4 along with a part of the data from Tables 2 and 3 for comparison.

TABLE 3.—*Comparison of floret and seed types of Kentucky bluegrass from seed heads infested and uninfested by the plant bug, Amblytylus nasutus.*

Test No.	Treatment	Floret and seed types: Undeveloped florets A	B	C	Shriveled seed D	E	Developed seed F	G	H	Undeveloped florets, %	Shriveled seed, %	Developed seed, %
A 23	Infested	68	206	3	3	0	0	0	0	98.9	1.1	0.0
A 24	Uninfested	22	11	3	28	29	26	14	119	14.3	22.6	63.1
A 25	Infested	29	80	7	41	92	17	1	6	42.5	48.7	8.8
A 26	Uninfested	5	4	3	25	36	33	25	150	4.3	21.7	74.0
A 27	Infested	38	31	11	50	41	1	7	34	37.6	42.7	19.7
A 28	Uninfested	0	3	16	30	33	45	36	42	9.3	30.7	60.0

DISCUSSION

The effect of feeding of *Miris dolobratus* and *Amblytylus nasutus* on seed heads of Kentucky bluegrass is shown by differences in percentages of floret and seed types (Tables 2 and 3) of infested and uninfested seed heads. The percentage of undeveloped florets from infested heads was much greater in every case than that of uninfested heads. Sometimes such a large percentage of the florets of infested heads did not develop that seed was not produced.

Analysis of seed from samples of infested and uninfested seed heads showed much fewer good seed in the infested samples. Weight and germination of seed from infested seed heads (Table 4) also were poorer.

TABLE 4.—*Comparison of floret and seed types of Kentucky Bluegrass from seed heads infested and uninfested by Miris dolobratus and Amblytylus nasutus and analyses of seed from the same samples.*

Test	Treatment	Floret and seed types, %: Undeveloped florets	Shriveled seed	Developed seed	Seed analysis, %: Seed	Chaff	Lbs. bu.	Germination, %: Seed	Seed in chaff
C 14	Infested	44.3	43.5	12.2	8.8	91.2	9	44	6
C 15	Uninfested	14.4	30.4	55.2	80.8	19.2	17	88	30
C 16	Infested	81.7	13.7	4.6	5.9	94.1	7	70	2
C 17	Uninfested	25.1	20.9	54.0	86.0	14.0	20	92	44
A 25	Infested	42.5	48.7	8.8	18.8	81.2	10	81	24
A 26	Uninfested	4.3	21.7	74.0	90.7	9.3	21	94	48

CONCLUSIONS

It was shown from a number of controlled tests made in 1942 that *Miris dolobratus* was a factor in reduced seed production and when abundant could prevent development of seed in Kentucky bluegrass. It was also shown that the plant bug *Amblytylus nasutus* could do about as much damage as could *M. dolobrutus*. Analyses of seed showed that when infested, bluegrass produced seed that weighed less and germinated less well than when uninfested.

The presence of *Amblytylus nasutus* in fields of bluegrass in large numbers in 1942 indicates that it must have been present in considerable numbers for several seasons. If this is true, it may have been responsible for much of the damage to the bluegrass seed crop instead of the better-known meadow plant bug, *Miris dolobratus*. It is very likely, however, that the lessened production of bluegrass seed in the last four or five years was due to the combined damage of the two plant bugs.

LITERATURE CITED

1. FLUKE, C. L. Wis. Agr. Exp. Sta. Bul. 455, Part 2:29–30. 1941.
2. GARMAN, H. Two important enemies of bluegrass pastures. Ky. Agr. Exp. Sta. Bul. 265:31–44. 1926.
3. OSBORN, HERBERT. Meadow plant bug. Jour. Agr. Res., 15:174–200. 1918.
4. SPENCER, J. T., and FERGUS, E. N. Floret and seed types in Kentucky bluegrass in relation to yield and quality of seed. Jour. Amer. Soc. Agron., 34:1035–1041. 1942.

LONG-TIME WHEAT VARIETY YIELD COMPARISONS[1]

H. H. LAUDE[2]

THE consideration of long-time wheat variety yield comparisons requires, first, a concept of what constitutes a long time. Examination of records at a number of the agricultural experiment stations in the United States revealed comparatively few records as long as 20 years, occasional comparisons as long as 30 years, and only rarely were varieties compared as long as 40 years. Probably most variety comparisons are for fewer than 10 years.

CONSTANCY OF COMPARATIVE VARIETY YIELDS

The difference between the yields of two varieties of wheat is not constant from year to year and for this reason agronomists usually evaluate varieties only on comparative tests for several years and often at several places in each year. Illustrations of differences in comparable average yields of varieties of winter wheat tested at various experiment stations for two parts of a continuous period of years are shown in Table 1.

TABLE 1.—*Variety yield comparisons for two parts of a continuous series of years at several experiment stations.**

Variety and station	First part		Second part	
	No. of years	Yield difference, bu.	No. of years	Yield difference, bu.
Cheyenne over Tenmarq, Manhattan, Kans.	6	+2.0	6	−1.4
Tenmarq over Blackhull, Manhattan, Kans.	9	+3.6	9	+0.2
Kanred over Turkey, Manhattan, Kans.	15	+3.1	16	+0.7
Poole over Fulcaster, Wooster, Ohio	20	+2.3	21	−1.4
Fulhio over Trumbull, Wooster, Ohio	12	+2.8	11	0.0
Purkof over Trumbull, Wooster, Ohio	7	+0.4	7	+4.4
Dietz over Fultz, College Park, Md.	10	+0.5	10	+3.4
Turkey over Indiana Swamp, Urbana, Ill.	13	+4.6	12	−1.7
Bluestem over Marquis, Pullman, Wash.	14	+2.5	13	−2.2

*The data for varieties at Wooster, Ohio, were supplied through the courtesy of Dr. C. A. Lamb, Department of Agronomy, Ohio Agricultural Experiment Station, and those for varieties at Pullman, Wash., for 1932 to 1940 through the courtesy of Professors E. G. Schafer and O. E. Barbee, Division of Agronomy, Washington Agricultural Experiment Station. The earlier Washington data were taken from Bulletins 207 and 289 of the Washington Agricultural Experiment Station (1, 12); the Illinois data from Bulletins 276 and 460 of the Illinois Agricultural Experiment Station (2, 13); and the Maryland data from Bulletin 297 of the Maryland Agricultural Experiment Station (7).

Cheyenne and Tenmarq were compared during 12 years at Manhattan, Kans. In the first 6 years Cheyenne averaged 2.0 bushels higher than Tenmarq, but in the last 6 years it averaged 1.4 bushels lower than Tenmarq. Twelve years may be too short a time in which

[1]Contribution No. 349, Department of Agronomy, Kansas Agricultural Experiment Station, Manhattan, Kans. Received for publication August 23, 1943.

[2]Agronomist.

to evaluate properly the comparative yield of varieties. Examination of longer periods shows, for example, that Tenmarq outyielded Blackhull an average of 3.6 bushels during the first 9-year period they were tested at Manhattan and that the two varieties yielded essentially the same during the second 9-year period. The average yield of Kanred at Manhattan during the first 15-year period it was tested was 3.1 bushels higher than that of Turkey, but during the next 16 years the difference was only 0.7 bushel in favor of Kanred. A still longer record is available at Wooster, Ohio, where Poole and Fulcaster have been tested 41 years. During the first half of that period the average yield of Poole was 2.3 bushels higher than that of Fulcaster, but during the last half Fulcaster outyielded Poole by an average of 1.4 bushels. A few other comparisons are shown in Table 1, and many more may be found in the records of experimental work.

It should not be assumed that a large proportion of variety comparisons show shifts of this kind; in fact, most of them probably do not. However, decided changes in average variety comparisons in different periods do occur so frequently as to make it difficult often to evaluate varieties correctly. Extreme caution is required in deciding upon superior varieties for recommendation to farmers because of changes in varietal relationship. The apparent fact that variety yield averages, even after long periods of testing, may not be constant, challenges the careful consideration of plant breeders and agronomists.

The length of time varieties should be compared is not standardized. Kemp and Metzger (7)[3] state that, "No matter how carefully the work has been conducted, many years of comparison are necessary before the relative yielding ability of a variety may be judged with any satisfactory degree of accuracy."

A study of the character of the changes in comparative variety yields may give suggestions not only regarding the length of time the experiments should be continued but also as to the degree of reliability of the results.

CHARACTER OF CHANGES IN VARIETY YIELD COMPARISONS

In the comparison of Kanred and Turkey at Manhattan it was found that the advantage of Kanred over Turkey averaged 3.8 bushels for the first 10-year period, 1.8 bushels for the second 10-year period, and 0.1 bushel for the third 10-year period. These data indicate a general trend in the relative yields of the two varieties. The yields of Kanred may be decreasing in relation to Turkey or the yields of Turkey increasing in relation to Kanred or both varieties may be responsible for the trend in relationship. Further examination indicates periods of 5 or 6 years with a different relation than prevailed either in the preceding or following periods of about 5 years, as shown by the 3-year moving average in Fig. 1. The general trend is shown in Fig. 1 by the straight sloping line or linear regression of the yield of Kanred in relation to that of Turkey during the 31 years they were tested. In this chart the years are in serial order as values

[3]Reference by number is to "Literature Cited", p. 160.

on the X or horizontal axis, and the deviations of the yield of Kanred from Turkey in bushels are plotted on the Y or vertical axis. The regression coefficient computed in this way is −0.15, signifying that the average decrease in the yield of Kanred compared to Turkey during the 31 years of testing was 0.15 bushel per year, or approximately 1 bushel every 7 years. The general trend relation between these two varieties is highly significant statistically. The curvilinear relation shown by the 3-year moving average line should not be overlooked.

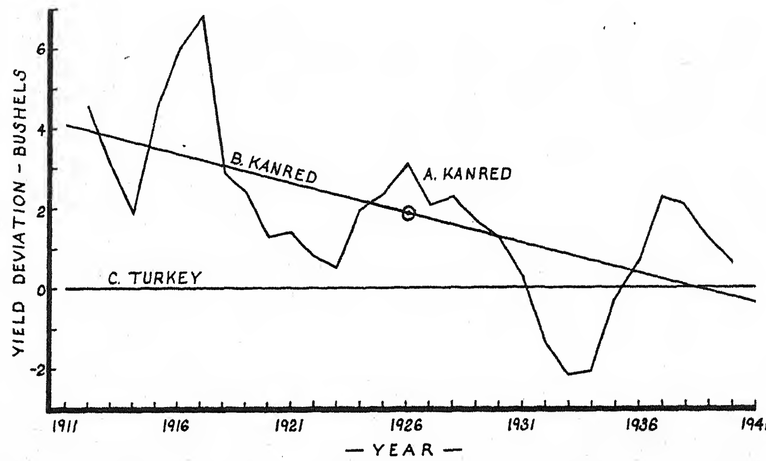


FIG. 1.—Yields of Kanred compared with Turkey wheat at Manhattan, Kans., 1911 to 1941. A, three year moving average of the annual deviation of Kanred yields from Turkey yields (C); and B, general trend of Kanred yields in relation to Turkey yields (C).

This trend relation between Kanred and Turkey was not limited to the experiments at Manhattan. A similar relation was shown by Salmon and Laude (11) where the results of 760 cooperative experiments on farms in all parts of Kansas from 1914 to 1930 are reported. Similar data for 387 comparisons from 1931 to 1940 were supplied by A. L. Clapp.[4] The average yield of Kanred compared to Turkey each year and the trend of yields for the 27-year period are shown in Fig. 2. The regression coefficient for the differences in yield from 1914 to 1940 is −0.15, showing that the yield of Kanred compared to Turkey decreased 0.15 bushel or about 1/7 bushel per year. This rate of decrease is the same as in the experiments at Manhattan and it also has a high statistical significance.

In most cases where important trends were noted in long-time varietal comparisons at various experiment stations in the United States essentially the same general trend appeared to continue throughout the entire period of test. However, the comparison of Poole and Fulcaster at the Wooster, Ohio, Experiment Station,[5] in-

[4]Unpublished data.

[5]LAMB, C. A. Comparative yields of varieties of wheat at Wooster, Ohio, 1900–1940. Unpublished data from Agron. Dept., Ohio Agr. Exp. Station.

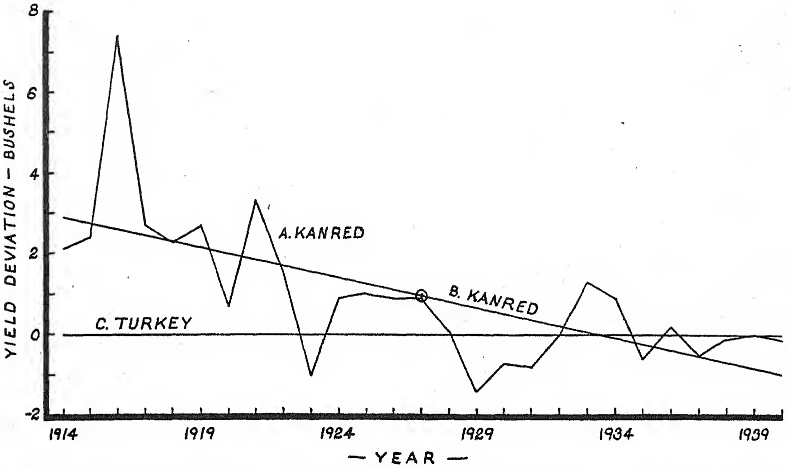


FIG. 2.—Relative yields of Kanred and Turkey wheat in 1,147 cooperative tests on farms in Kansas from 1914 to 1940. A, deviation of the average annual yields of Kanred from Turkey (C); and B, general trend of Kanred yields in relation to the yields of Turkey (C).

cluded two periods of considerable length with apparently different trends. These are illustrated in Fig. 3 where the computed trend for each period and the 3-year moving averages of difference in yield between the two varieties are shown. During the first period of 20 years, 1900 to 1919, inclusive, the yield of Poole averaged higher than Fulcaster and increased in relation to Fulcaster at the yearly rate of 0.22 bushel. In the other period of 19 years, 1922 to 1940, inclusive, Poole averaged lower in yield than Fulcaster and the trend in rela-

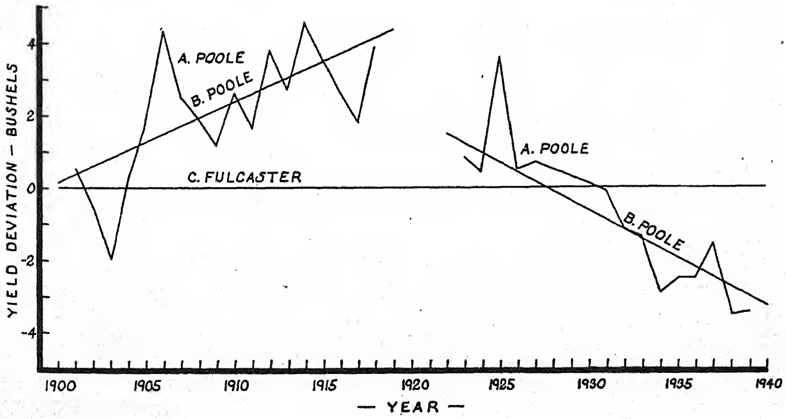


FIG. 3.—Yield trends of Poole in relation to Fulcaster wheat at the Wooster Ohio Agricultural Experiment Station during two periods, 1900 to 1919 and 1922 to 1940, inclusive. A, 3-year moving average of the annual deviation of yields of Poole in relation to yields of Fulcaster (C); and B, general trend of the yields of Poole in each of two periods in relation to the yield of Fulcaster (C).

tion to Fulcaster was downward at the annual rate of 0.26 bushel. Both of these trends are statistically significant at the 5% level.

The foregoing illustrations indicate that variety yield comparisons may not remain constant. The varietal relationship is affected not only by year-to-year influences but also by long-time influences. These influences appear to cause both irregular, fluctuating yield relationships and gradual or trend changes in the comparative variety yields. The same linear trend may prevail throughout the entire experiment or only through a portion of it.

CAUSES OF CHANGE IN COMPARATIVE YIELDS OF VARIETIES

It would appear that changes in long-time comparative yields of varieties must be accounted for by changes either in the environment or in one or both of the varieties concerned, or in both the environment and one or both varieties.

ENVIRONMENTAL FACTORS

Kemp and Metzger (7) found that the Fultz type of wheat outyielded Fulcaster from 1891 to about 1904 but that subsequently Fulcaster yielded more than Fultz. The authors account for this shift in variety relationship by the development in Maryland of *Septoria nodorum*, a disease to which wheat of the Fultz response type is much more susceptible than that of the Fulcaster type. Consequently, when the disease became prevalent and severe, the more susceptible type was depressed in yield below Fulcaster. It can be assumed that insect pests, when prevalent, may affect variety yield comparisons as do diseases.

Gradual changes in climatic conditions may account for similar shifts if the changes are such as to favor or hinder one variety compared to another. Normal variations in climatic conditions from season to season or between periods of several seasons probably are often responsible for changes in comparative yields of varieties. When variety yield comparisons change gradually it seems necessary to assume that the responsible seasonal factors have also changed gradually. That is, the trend in comparative yields may be expected to follow corresponding trends in the causal climatic factors. Proof of such causal relationships is often difficult. Future research should include the objective of determining year-to-year trends of environmental factors that have a differential influence on varieties.

Kiesselbach, Anderson, and Suneson (9) emphasize the fact that seasonal variability in climatic and soil conditions and in the prevalence of plant disease and insect pests influence varietal comparisons. They state that, "This may be illustrated by the comparison of four Turkey selections with the parent variety which they surpassed in yield by 14 to 21% during the 5 years 1913 to 1917 but failed to surpass during the 5 years 1928 to 1932." In addition to that observation it is interesting to note that the relative yields of the four Turkey selections not only show a difference between the two widely separated 5-year periods but also show a gradual trend from the earlier to the later period in the two intervening 5-year periods. For example,

Nebraska No. 6 (9) started with a relative yield of 131 in comparison with 100 for the original Turkey in the nursery tests of 1910–12. Its relation to Turkey in the successive 5-year periods to 1932 was 121, 103, 104, and 97, respectively. The corresponding relative yields of Turkey Selection No. 60 were 133, 114, 105, 104, and 100 for the several periods. The other two selections also have a downward trend throughout the 33-year period in relation to the original Turkey. These data, therefore, appear to indicate trend changes which, as was suggested by the authors, may be due entirely to changes in the environment.

It appears evident that environmental conditions, and particularly climatic conditions, have important influences on comparative variety yields, and that changes in the relative yields of varieties may be accounted for by changes in the environment. If such varietal changes follow trends, it seems logical that the causal environmental factors must also be changing in the same manner.

CHANGE WITHIN VARIETIES

Another possible cause for changes in the relative yields of varieties is that one or both of the varieties are changing. A variety may be altered as a result of changes either within the plant or in the population of plants.

In the population. Laude and Swanson (10) found that in populations of winter wheat consisting of a mixture of two varieties, changes in the relative proportions of varieties occurred from year to year. The changes were toward a higher proportion of the better adapted variety and resulted both from successful competition among plants in the vegetative stage and from larger production of the surviving plants. Harlan and Martini (4) demonstrated that changes of this kind take place in barley. Changes in the population of wheat might be expected, in some cases at least, to eliminate the less productive strains. Consequently, a variety that includes several to many strains might be expected to increase in relative yield over varieties that include only one strain. On this hypothesis the trend in relative yields of Kanred and Turkey in Kansas might be accounted for by improvement of Turkey through natural elimination of the less productive strains. Many shifts in other variety yield comparisons might be explained in a similar way for it is doubtful whether varieties produced by any method of wheat improvement are entirely homogeneous with respect to all factors that influence their growth and yield. Therefore, the influence of environmental conditions may cause an increase in the proportion of plants having certain factors and a decrease of those possessing different factors so as to change the relative yield.

Within the plant. Trends in variety yield comparisons may furthermore be accounted for by changes within the plant. The relatively high yields in the early years of some hybrids would suggest the possibility of heterosis being manifested for several generations. Engledow and Pal (3) demonstrated hybrid vigor in wheat and showed that its influence decreased but continued at least as long as the third generation after crossing. Jones (5) has worked out the

theoretical proportion of heterozygous individuals in each generation of self-pollinated plants following a cross and for various numbers of allelomorphic pairs of factors. Where 10 to 15 pairs of factors are involved about one-fifth of the individuals in the sixth generation and a small proportion in the tenth generation are heterozygotes. In actual experiments with corn, however, Jones (6) reported that the yield of inbred lines continued to decline for 20 years after selfing was started, but that subsequent generations of the inbred lines appeared to be uniform for all visible characters and homozygous for all loci that would affect hybrid vigor.

If perchance hybrid vigor in wheat influences the yield for as long as 15 or 20 years following the cross, a basis would be afforded to account for the downward yield trend of many new varieties. Such a trend occurs so frequently as to demand attention and study. At the Kansas Agricultural Experiment Station, for example, the yields of Kanred, Blackhull, and Tenmarq have decreased in relation to the yield of Turkey. It is possible that the relative yield of Turkey has increased to account for these trends. However, when each of the varieties was compared with the next preceding variety in order of introduction, a decrease in relative yield was found for each new variety compared with the next older one. The relative decrease of Kanred over Turkey from 1911 to 1941 has already been given at 0.15 bushel per year. Since Blackhull was first included in the tests in 1919, it has decreased in relation to Kanred at the average annual rate of 0.05 bushel, and Tenmarq since it was first tested in 1924 decreased in relation to Blackhull at the annual rate of 0.15 bushel.

Tenmarq is known to be of hybrid origin. It was developed from a cross made in 1917 and resulted from a plant selected in 1921; thus, it traces to hybrid origin probably in 1917, although possibly as late as 1920. The comparative plot tests began in 1924. For 9 years Tenmarq yielded more than Turkey each year, the average increase being 6.6 bushels. During the next 9 years it averaged 1.7 bushels higher than Turkey and yielded less in three of the seasons. Its yield in relation to Turkey has decreased at the average rate of 0.26 bushel per acre per year. The downward trend in the yield of Tenmarq compared to Turkey can be explained by assuming heterosis to be a factor for about 20 years following the cross.

Another illustration of the downward trend of a hybrid in relation to an old variety is found in the comparison of Triplet and Fortyfold at the Pullman, Wash., Experiment Station (1, 12).[6] Triplet is the result of a cross and was first grown as a strain at Pullman in 1910. Plot yields are available from 1914 to 1940. The average increase of Triplet over Fortyfold during the first 10 years was 14.5 bushels and during the second 10 years 7.5 bushels. The trend relation of Triplet compared with Fortyfold shown in Fig. 4 can be accounted for by hybrid vigor in Triplet if it could be assumed that heterosis influences yields for about 20 years.

[6]Also unpublished data from E. G. Schafer and O. E. Barbee of the Agronomy Division, Washington Agricultural Experiment Station, on comparative yields of varieties of wheat at Pullman, Wash., 1932–40.

There is some probability that varieties originated by selection may be of recent hybrid origin. Plants influenced by heterosis are more likely to be chosen than homozygous plants. Kanred is one of many varieties developed by head selection. In the case of Kanred repeated head selections were made from nursery rows for several years. Assuming only a slight amount of crossing in adjacent rows of wheat, together with the practice of repeated head selection in the nursery, it appears that there would be a high probability of selecting a hybrid plant in 2 to 4 years. Similarly, there is some possibility that Blackhull, Cheyenne, and many other varieties may have been selections from recent hybrid origin. Granting that such probability exists, the trends of relative yields of these varieties may be at least partly accounted for on the hypothesis that heterosis persists for a considerable number of generations.

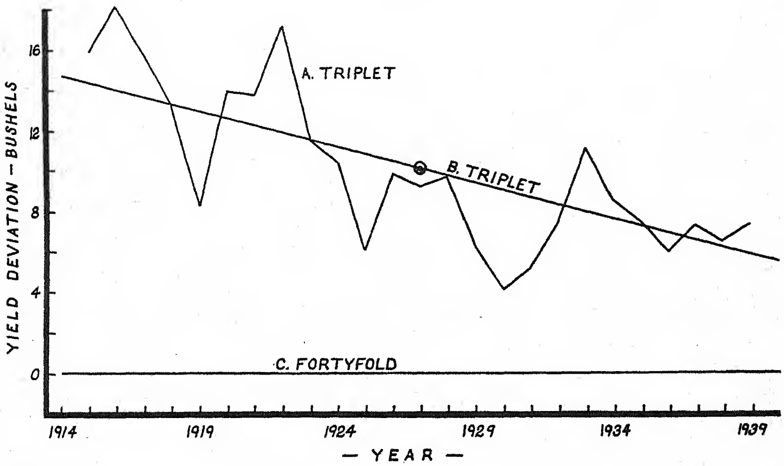


FIG. 4.—Comparative yields of Triplet and Fortyfold wheat, Pullman, Wash., 1914 to 1940, inclusive. A, 3-year moving average of difference in yield between Triplet and Fortyfold (C); and B, general trend of the yield of Triplet in relation to the yield of Fortyfold (C).

Kiesselbach (8) reported the annual yields of 31 strains of Turkey wheat compared with the original Turkey from which they were selected in 1907 at Lincoln, Nebr. Examination of the average relative yields for the 5 years, 1914–18, and the 4 years, 1919–22, shows that 27 of the 31 strains yielded lower in relation to the original Turkey in the second period than in the first, indicating that either the relative yield of the selections decreased from 1914 to 1922 or the yield of the original Turkey increased in relation to the selections. It is not possible to state which of these changes took place; perhaps both were involved. The assumption on the one hand that Turkey improved and on the other that the newly developed varieties decreased in yield may perhaps be accepted with about equal logic.

If heterosis in wheat is found to persist for a considerable number of generations, its influence might be preserved and extended by storing seed of an early generation for perhaps 10 years, after which it would be planted and increased for distribution to replace the regular crop. Thus a new start would be made with seed 10 generations closer to the original hybrid.

SUMMARY

From the foregoing discussion it appears that comparative yields of wheat varieties in many instances do not continue constant during long periods of testing. In some cases the change in the comparative yield of varieties is gradual. Varietal differences may either increase or decrease during long periods of testing.

The change in the comparative yields of varieties is assumed to be the result of changes either in the environment, including meteorological, biological, and nutritional factors, or in one or both of the varieties compared, or in the environment and the varieties.

If trend changes in the comparative yields of varieties are to be explained by environmental influences, it appears requisite that corresponding trend changes should prevail in the causal environmental factors.

Varietal changes which may influence long-time comparisons must apparently be caused either by changes in the population of one or both of the varieties or by changes within the protoplasm of the plant of one or both varieties.

The evidence is not conclusive as to where the causes lie which result in changes in relative yields of some varieties. Probably several causes are involved in different cases. Further research would appear to be desirable in the attempt to gain a better understanding of how and why comparative yields of varieties often do not continue constant for long periods of time.

LITERATURE CITED

1. BARBEE, O. E. A comparison of wheat varieties in eastern Washington. Wash. Agr. Exp. Sta. Bul. 289:1–44. 1933.
2. DUNGAN, GEORGE H., BURLISON, W. L., KOEHLER, BENJAMIN, and BONNETT, O. T. Winter wheat varieties for Illinois. Ill. Agr. Exp. Sta. Bul. 460:87–104. 1939.
3. ENGLEDOW, F. L., and PAL, B. P. Investigations on yield in cereals; hybrid vigour in wheat. Jour. Agr. Sci., 24:390–409. 1934.
4. HARLAN, H. V., and MARTINI, M. L. The effect of natural selection in a mixture of barley varieties. Jour. Agr. Res., 57:189–199. 1938.
5. JONES, D. F. Selection of pseudo-starchy endosperm in maize. Genetics, 4:364–393. 1919.
6. ———. Continued inbreeding in maize. Genetics, 24:462–473. 1939.
7. KEMP, W. B., and METZGER, J. E. Environmental factors influencing wheat production in Maryland. Md. Agr. Exp. Sta. Bul. 297:125–173. 1928.
8. KIESSELBACH, T. A. Winter wheat investigations. Nebr. Agr. Exp. Sta. Res. Bul. 31:1–149. 1925.
9. ———, ANDERSON, ARTHUR, and SUNESON, C. A. Winter wheat varieties in Nebraska. Nebr. Agr. Exp. Sta. Bul. 283:1–24. 1933.
10. LAUDE, H. H., and SWANSON, A. F. Natural selection in varietal mixtures of winter wheat. Jour. Amer. Soc. Agron., 34:270–274. 1942.

11. SALMON, S. C., and LAUDE, H. H. Twenty years of testing varieties and strains of winter wheat at the Kansas Agricultural Experiment Station. Kans. Agr. Exp. Sta. Tech. Bul. 30:1–73. 1932.

12. SCHAFER, E. G., GAINES, E. F., and BARBEE, O. E. Wheat varieties in Washington. Wash. Agr. Exp. Sta. Bul. 207:1–31. 1926.

13. STARK, ROBERT W. Productiveness of varieties of winter wheat in Illinois. Ill. Agr. Exp. Sta. Bul. 276:1–35. 1926.

RELATIVE PALATABILITY OF EIGHT GRASSES USED IN RANGE RESEEDING[1]

RICHARD M. HURD AND C. KENNETH PEARSE[2]

BEFORE a grass is recommended for range reseeding it not only must be able to establish and maintain itself, but it must also be palatable to the class of livestock grazing the range. For some grasses, particularly those which have proved valuable as cultivated pasture plants, the palatability is fairly well known. Much more specific information on relative palatabilities as a whole is needed, however, as a basis for making fully satisfactory seeding mixtures and sound reseeding programs. To help obtain this information, grazing tests were conducted by the Intermountain Forest and Range Experiment Station at Ogden, Utah, on eight important species extensively used in range reseeding.

The experimental area is located in the mountain brush zone at an elevation of 5,200 feet near Ogden, Utah. The average annual precipitation is approximately 29 inches. Typical representatives of the native vegetation are Gambel oak, *Quercus gambeli;* big sagebrush, *Artemisia tridentata;* mountain snowberry, *Symphoricarpos oreophilus;* and serviceberry, *Amelanchier alnifolia*. Quaking aspen, *Populus tremuloides*, is present, principally on the north slopes. The more abundant herbs are bluegrasses, *Poa* spp.; mountain brome, *Bromus carinatus;* slender wheatgrass, *Agropyron trachycaulum;* arrowleaf balsamroot, *Balsamorhiza sagittata;* and sticky geranium, *Geranium viscossissimum*.

Seven of the 17 acres of the fenced experimental tract consisted of a gently sloping "flat" which had at one time been cleared of sagebrush, plowed, and seeded to alfalfa. Although good stands had been secured, the field proved uneconomical for harvesting because of its small size and inaccessibility and was abandoned for crop production. By 1936 excessive grazing and trampling had completely eliminated the alfalfa, leaving annual weeds as the sole cover. After exclusion of the livestock, the tract was disked and sown to a number of perennial grasses as one of a series of species adaptability trials. In the spring of 1941, when the grazing tests were initiated, many of the plots of reseeded species had been producing vigorous stands for several years.

The eight species which produced good stands and which were used in the palatability test included: crested wheatgrass, *Agropyron cristatum;* bluestem wheatgrass, *Agropyron smithi;* bearded bluebunch wheatgrass, *Agropyron spicatum;*[3] slender wheatgrass, *Agropyron trachycaulum;* tall oatgrass, *Arrhenatherum elatius;* mountain brome, *Bromus carinatus;* smooth brome, *Bromus inermis;* and orchardgrass, *Dactylis glomerata*.

---

[1]Contribution from the Intermountain Forest and Range Experiment Station, Forest Service, U. S. Dept. of Agriculture, Ogden, Utah. Received for publication August 24, 1943.

[2]Junior Range Examiner and Conservationist, respectively.

[3]This contained a small amount of the closely related beardless bluebunch wheatgrass, *Agropyron inerme*.

All of these grasses were growing singly in 0.02-acre plots. For every species there were at least two and often four plots located at random. Additional larger plots of crested wheatgrass, slender wheatgrass, and mountain brome from 0.2 to 0.8 acre in size had been established.

EXPERIMENTAL METHODS

Uniform 2-year-old beef steers were permitted to graze freely over the plots during the spring seasons of 1941 and 1942. The relative preference with which they utilized the different grasses was determined by the "ocular estimate by plot" method which has been described by Pechanec and Pickford.[4] A small temporary enclosure was placed on two plots of each species, the ungrazed grass of which served as a basis in determining the volume of herbage removed (Fig. 1).

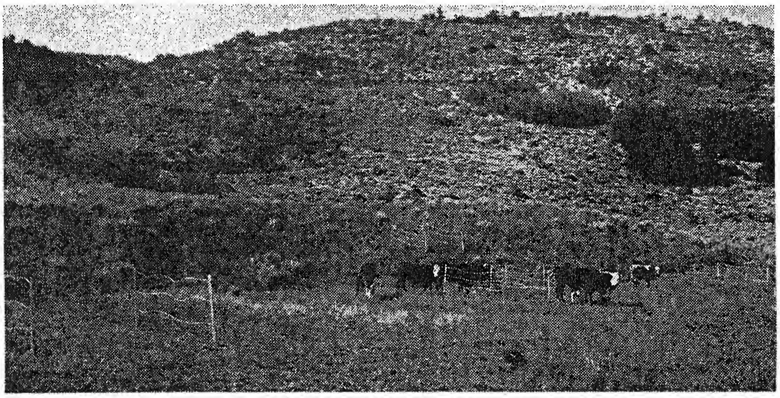


FIG. 1.—Eight grasses were sown in individual plots located on a small level area within the mountain brush zone. Small temporary enclosures provided ungrazed plants which facilitated the estimation of utilization.

RESULTS

Data secured for both years exhibit comparable trends with only a few minor variations. However, since the 1942 data were more complete and reliable, they are used throughout. The stage of development varied considerably among the species when grazing started; crested wheatgrass, orchardgrass, and bearded bluebunch wheatgrass were 8 to 9 inches tall, tall oatgrass was in the boot and 15 inches high, slender wheatgrass was 6 inches tall, smooth brome 7 inches, bluestem wheatgrass 5 inches, and mountain brome at 14 inches was heading out. All of the species had made good growth and grazing probably should have started earlier. Utilization estimates were first made on May 25 (4 days after grazing started), again on June 3 and June 11, and were concluded on June 23 (Table 1, and

[4]PECHANEC, JOS. F., and PICKFORD, G. D. A comparison of some methods used in determining percentage utilization of range grasses. Jour. Agr. Res., 54:753–765. 1937.

TABLE 1.—*Average of utilization estimates, 1942, to nearest 5%.*

Date	May 25	June 3	June 11	June 23
Days after the initiation of grazing	4	13	21	33
Mountain brome	40	60	70	80
Smooth brome	55	60	80	90
Tall oatgrass	55	65	80	90
Orchardgrass	45	60	80	90
Bearded bluebunch wheatgrass	5	5	20	45
Bluestem wheatgrass	5	10	40	55
Crested wheatgrass	5	30	55	70
Slender wheatgrass	50	60	85	85

Fig. 2). The steers were removed from the pasture on June 24. By this time all ungrazed plants had produced heads and some species had made seed.

The varying percentages of utilization reflect the palatability of any particular species. Palatability ratings made soon after grazing started and before the choice of species became limited showed that bearded bluebunch, bluestem, and crested wheatgrass have comparatively low palatability. In comparison, orchardgrass, tall oatgrass, mountain brome, smooth brome, and slender wheatgrass are highly palatable. This characteristic is maintained throughout the grazing period. As the more palatable grasses become completely

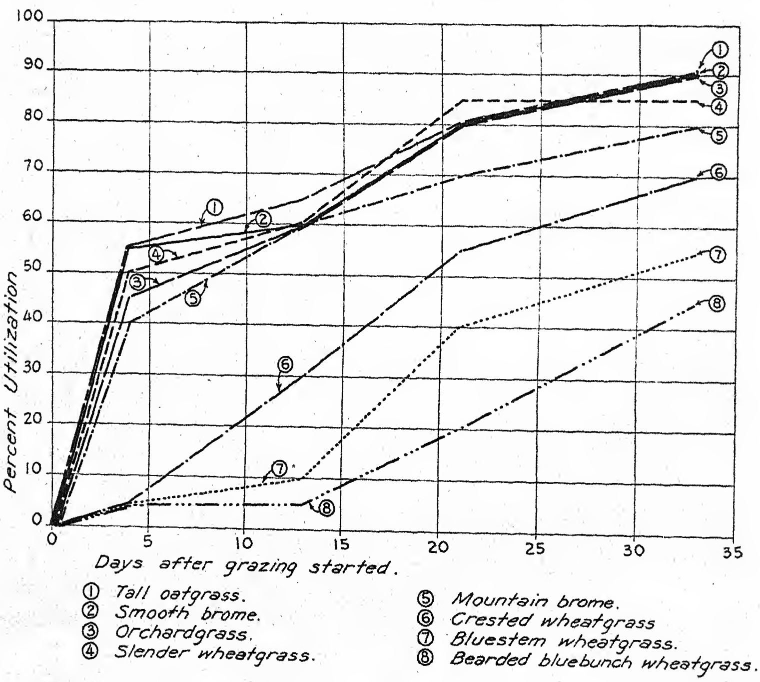


FIG. 2.—Trends in the utilization of eight grasses.

utilized, the less palatable (crested, bluestem, and bearded bluebunch wheatgrass) are taken in greater abundance to compensate for the smaller amount of more desirable herbage. It became evident that crested wheatgrass was somewhat more palatable than the native bluestem and bearded bluebunch wheatgrasses. Had the grazing been initiated slightly earlier in the season, crested wheatgrass may have exhibited a higher palatability.

The nearly complete utilization of the five highly palatable species was undoubtedly detrimental to the grazed plants. Lighter utilization would be necessary from the standpoint of good range and pasture management. This would have required the removal of the steers on, or probably even before, the twenty-first day to protect the more palatable species from injurious utilization.

DISCUSSION

When mixtures are being made for reseeding range or pasture land, the palatability of the various constituents should be kept in mind. The inclusion of one or two extremely palatable species with those having a lower preference will inevitably result in overutilization and eventual elimination of the favored species. It was observed in this grazing study that the steers would thoroughly cover the plots of orchardgrass, smooth brome, tall oatgrass, and slender wheatgrass in search of the smallest spear before moving on to the less palatable species that still furnished a considerable amount of easily available forage. Grazing of a range that has been seeded to a mixture must be correctly managed to perpetuate the preferred species.

Combination of the less palatable with the more palatable grasses tested in this study is undesirable for reasons other than the one stated above. Crested, bluestem, and bearded bluebunch wheatgrasses are most useful on valley and foothill ranges that are too dry for the more palatable species. They are not generally recommended for ranges with better moisture and soil conditions where the more productive species, which also are more palatable, are well adapted.

There may be some opportunity of obtaining better distribution of livestock on a reseeded range and hence more uniform utilization of the forage by planting the more palatable species away from water, on the slopes, and on other lightly used portions of the range, and the less palatable ones where livestock naturally congregate. The usefulness of such a plan would be limited, of course, by the growth requirements of the species concerned, but it seems to warrant some consideration in preparing reseeding plans.

SUMMARY

The relative palatability of eight grasses was investigated by grazing tests using 2-year-old steers. The percentage utilization of the grasses was estimated four times during the 33-day grazing period. Of the eight species, tall oatgrass, smooth brome, orchardgrass, slender wheatgrass, and mountain brome were the most palatable. Crested wheatgrass, bluestem wheatgrass, and bearded bluebunch wheatgrass were less palatable and were sought after by the livestock in the order given.

YIELD AND BUSHEL WEIGHT OF CORN GRAIN AS INFLUENCED BY TIME OF PLANTING[1]

George H. Dungan[2]

THE exigencies of the season frequently make late planting of corn unavoidable. To escape maximum injury from certain insects, late planting is sometimes desirable. Experienced corn growers in the Corn Belt know, however, that if a stand can be obtained, moderately early planting is advisable. Whenever planting is delayed because of unfavorable weather, there is no object in trying to estimate the loss of yield occasioned by late planting; but when delay in planting is deliberate in an attempt to reduce disease and insect losses, then the question of sacrifice in yield resulting from this delay is pertinent. Will withholding planting for two or three weeks after the soil is ready cause more loss in the crop than would result from the insect or disease when the crop is planted early?

Delayed planting of corn has been frequently recommended as a means of preventing severe damage from the first generation of the European corn borer. Some data on time of planting corn obtained by the Illinois Agricultural Experiment Station throw light on the wisdom of this recommendation. Date of planting tests were made during the 5-year period, 1927–31. The tests were made before the borer was present in the state and the results are not complicated by the damaging influence of this insect as they would be if conducted now. The corn used was open-pollinated varieties, but there is reason to believe that essentially the same response would have been obtained with hybrids of the same maturity groups.

METHOD

The corn used in the tests was open-pollinated varieties differing in length of season required for maturity. Short-seasoned varieties in northern Illinois tests included All Dakota, Brookings 86, Falconer, Pioneer, Square Deal, Dakota Sunshine, and Payne. Mid-season varieties were Gunn Western Plowman, Pride of the North, Substation White, Substation Yellow, Duncan Yellow Dent, M.A.C. No. 1, Murdock Yellow Dent, Kossuth Reliance, Wimple Yellow Dent, Silver King, and Golden Jewell. Full-season varieties were Station Yellow Dent, Golden King (Mills), Hunt White Dent, Funk 90 Day, and Krug (Pfister).

In central Illinois tests, the mid-season varieties used were Funk 90 Day, Krug (Pfister), Woodburn Yellow Dent, Clarage, and Medina Pride. The full-season varieties were Champion White Pearl, Sommer Yellow Dent, Station Yellow Dent, Illinois Two-Ear, and Eversole White Dent.

Plantings on the two fields were made at three dates as shown in Table 1.

Four blocks, 25×40 hills, were planted at each date. Each variety occupied 1 row 25 hills long. Although a check planting of Station Yellow Dent was made in every fifth row in some years and in every second row in other years at Urbana, the yields of the varieties were not adjusted to the check. The variety used as the check at DeKalb was Gunn Western Plowman.

[1]Contribution from the Department of Agronomy, Illinois Agricultural Experiment Station, Urbana, Ill. Published with the approval of the Director. Received for publication September 4, 1943.

[2]Chief in Crop Production.

TABLE 1.—*Planting dates at DeKalb and Urbana, Ill.*

DeKalb		Urbana	
Range	Average	Range	Average
May 6–19	May 11	May 1–5	May 2
May 21–June 1	May 27	May 21–23	May 21
June 3–11	June 7	June 10–13	June 11

The yields of the varieties in the same maturity range have been averaged for each year. The results obtained for the second and third plantings have been compared with those from the first planting and those from the third planting with those from the second. The significance of the difference has been tested by determining the value of t at the 5% and 1% points.

RESULTS

A summary of the yield data, the bushel weight, and the percentage of water-free shelled corn is shown for northern Illinois in Table 2 and for central Illinois in Table 3. While the several varieties differed somewhat from one another in their response to time of planting, the direction of the trend was the same in almost all cases.

TABLE 2.—*Performance of corn as influenced by time of planting at DeKalb in northern Illinois, 5-year average.*

Performance factor	First planting, May 11	Second planting, May 27	Second planting compared with first	Third planting, June 7	Third planting compared with first	Third planting compared with second
Short-season varieties (7)						
Yield of shelled corn, bu..	26.4	30.8	+4.4**	27.3	+0.9	−3.5 *
Bushel weight of shelled corn, lbs.	57.1	56.6	−0.5	55.3	−1.8**	−1.3**
Water-free shelled corn, %	64.6	63.2	−1.4	60.5	−4.1**	−2.7**
Mid-season varieties (11)						
Yield of shelled corn, bu..	45.0	46.4	+1.4	38.9	−6.1**	−7.5**
Bushel weight of shelled corn, lbs.	53.8	51.9	−1.9**	47.7	−6.1**	−4.2**
Water-free shelled corn, %	59.8	57.3	−2.5**	51.6	−8.2**	−5.7**
Full-season Varieties (5)						
Yield of shelled corn, bu..	49.6	47.4	−2.2	39.3	−10.3**	−8.1**
Bushel weight of shelled corn, lbs.	55.0	52.5	−2.5**	47.3	−7.7**	−5.2**
Water-free shelled corn, %	59.6	56.1	−3.5**	48.3	−11.3**	−7.8**

*Exceeds the 5% point.
**Exceeds the 1% point.

Short-season and mid-season varieties produced their highest yields at DeKalb at the second planting, May 27. The short-season varieties produced the lowest yields at the first planting, while the

TABLE 3.—*Performance of corn as influenced by time of planting at Urbana in central Illinois, 5-year average.*

Performance factor	First planting, May 2	Second planting, May 21	Second planting compared with first	Third planting, June 11	Third planting compared with first	Third planting compared with second
			Mid-season Varieties (5)			
Yield of shelled corn, bu. .	64.7	61.6	−3.1*	47.8	−16.9**	−13.8**
Bushel weight of shelled corn, lbs.†	57.7	57.5	−0.2	55.5	−2.2**	−2.0*
Water-free shelled corn, %†	69.1	65.1	−4.0*	60.2	−8.9**	−4.9*
			Full-season Varieties (5)			
Yield of shelled corn, bu. .	69.3	64.4	−4.9	47.0	−22.3**	−16.4**
Bushel weight of shelled corn, lbs	58.4	57.0	−1.4*	54.0	−4.4**	−3.0**
Water-free shelled corn, %	65.4	60.2	−5.2*	52.4	−13.0**	−7.8**

*Exceeds the 5% point.
**Exceeds the 1% point.
†Four varieties instead of five were included in the bushel weight and water-free shelled corn averages of mid-season varieties.

mid-season and full-season varieties produced the lowest yields at the third planting. The use of short-season varieties for late planting would not seem justifiable from the standpoint of yield according to these data. The quality of corn produced by short-season varieties as measured by bushel weight and percentage of water-free shelled corn at husking time was higher in every case than that produced by mid-season and full-season varieties.

Full-season varieties gave their highest average yield from the first planting. The yield from the second planting was only 2.2 bushels less, however. The yield of mid-season and full-season varieties dropped off sharply and significantly for the June 7 planting, and the yield of full-season varieties fell off more comparatively than that of the mid-season varieties.

The June 7 planting at DeKalb gave significantly lower yields than the May 27 planting in the case of all maturity groups. The drop increased with later maturity, being 3.5 bushels for short-season varieties, 7.5 bushels for mid-season varieties, and 8.1 bushels for full-season varieties.

In central Illinois the May 2 planting gave the highest average yields in both maturity groups. The May 21 planting produced distinctly higher yields than the June 11 planting. Bushel weight and percentage of water-free shelled corn were also highest for the first planting. These quality factors showed the sharpest decline, however, for the last planting.

DISCUSSION

Late planting affects the corn crop in a number of ways. It is usually associated with severe lodging before harvest and with a

shortened vegetative period. Three weeks' difference in planting date separates tasseling dates only about a week, as is shown in Fig. 1. Perhaps the most important influence in delaying planting is its effect on yield and quality of grain. Ordinarily full-season corn will produce its maximum yield when planted at the earliest date. Sometimes, however, a period of intense heat and drouth at the critical period injures the early planted crop more than that planted later.

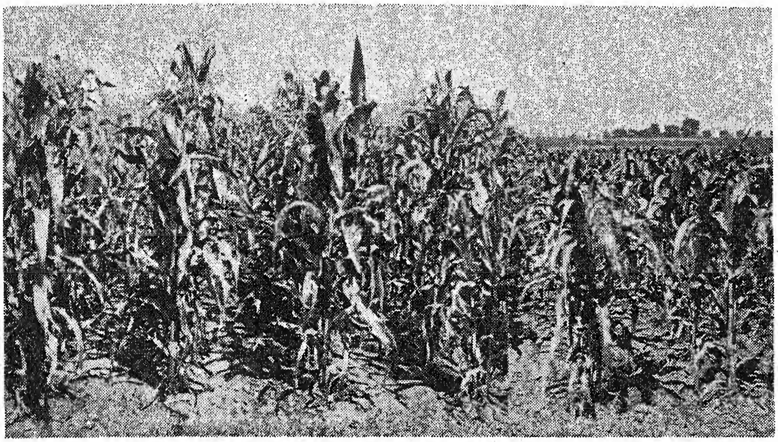


FIG. 1.—*Left*, corn planted at Urbana May 1; *center*, corn planted May 21; and *right*, corn planted June 10. Photographed July 22, 1931.

Ordinarily the best guide to follow in planting corn is the practice that gives the best results over a period of years. In the northern Illinois test, plantings of mid-season and full-season varieties made on May 11 and May 27 gave approximately the same yield. It appears to be more important to plant full-season varieties early than it is for varieties requiring a shorter time for maturity. There was a tendency for the yields from full-season varieties to be higher for all plantings than yields from earlier varieties. Perhaps a thicker planting of short-season varieties would have offset this tendency somewhat.

The quality of the grain resulting from late planting at DeKalb was lower for full-season than for short-season and mid-season corn. The same relationship held true at Urbana between full-season and mid-season varieties.

When the destructiveness of the corn borer in any locality equals the yield reduction caused by delayed planting, the advisability of delayed planting as a control measure should be considered. The presence of the multiple generation strain of the insect complicates the problem considerably. Delayed planting enables the corn to escape the heaviest infestation of the first generation, but it brings the plants into an attractive stage at the time eggs are being laid for the second generation. It appears, however, that a given level of infestation will cause more harm when the corn plants are small

than when they are large. It, therefore, seems more advantageous to avoid the first generation of borers than the second. This question will need to be studied in each locality, since the seasonal history of the multiple generation strain of the insect may vary greatly.

The farmer who practices good crop and soil management can get fairly good yields even though he is forced to plant his corn late. For instance, at DeKalb the yield from June 7 planting of full-season varieties was 39.3 bushels per acre. At Urbana the average yield for plantings made June 11 was 47 bushels per acre.

SUMMARY

Yield and quality tests of short-, mid-, and full-season corn varieties planted at the three different dates in northern and central Illinois led to the following results:

1. An intermediate planting date proved best for short-season varieties in northern Illinois.

2. Early planting of full-season varieties gave best yields in both northern and central Illinois. In northern Illinois May 27 planting reduced the yield 2.2 bushels under May 11 planting, and June 7 planting reduced it 10.3 bushels. At Urbana in central Illinois May 21 planting reduced the yield 4.9 bushels under May 2 planting, and June 11 planting reduced it 22.3 bushels.

3. Quality of grain as measured by bushel weight and percentage of water-free shelled corn was reduced by delayed planting in all cases.

In view of the detrimental influence of late planting on the yield and quality of the crop, it appears that the use of this method for the reduction of insect and disease damage should be adopted with some caution.

NOTES

A METHOD OF SEEDBED PREPARATION AND RESEEDING DETERIORATED RANGE LANDS

BECAUSE of the wide variety of conditions found in the semidesert grassland with regard to distribution and amount of seasonal rainfall, character of soils, and degree to which soils are already eroded, it is difficult to develop standard range seeding prac-

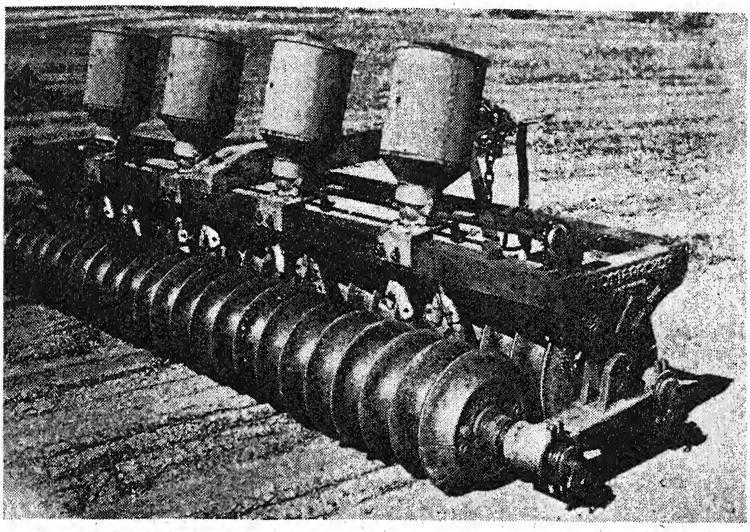


FIG. 1.—*Upper*, the cultipacker-seeder; *lower*, rows of Lehmann lovegrass, *Eragrostis lehmanniana*, seedlings established in seeded area.

tices. However, for shallow upland soils, as distinguished from alluvial soils which are deep and receive flood water from adjacent slopes, several principles seem to have general application. First, a firm rather than a loose seedbed is essential for conservation of moisture in the surface soil. This is necessary to assure establishment of grass seedlings when rainfall is poorly spaced. Second, planting of seed in a groove rather than on the flat favors germination of seed and establishment of seedlings. Third, shallow, closely spaced contour furrows retard runoff and increase intake of water into the soil.

Fig. 1 shows the machine which was assembled and used in field tests during the summer of 1943. Four Planet Jr. seed hoppers were mounted on an ordinary 8-foot tandem cultipacker with the wheels set to track each other. The hoppers are manufactured with a double seed delivery spout. In order to provide a wider ground seed coverage from each hopper, each spout was again divided so that four delivery channels were provided. The seed agitators in the base of each hopper are connected in series by short sections of pipe. By hooking up a bicycle chain with sprockets attached to the end of the shaft and an end cultipacker wheel, motive power for the agitator is provided. The seed cutoff plates in all hoppers are also connected in series so that they may be controlled as a unit. The seed is dropped into the small grooves made by the front cultipacker wheels and pressed into the soil by the rear wheels.

Advantages of the unit for range seeding include the following: (1) It is easily assembled from new or used parts. (2) It is rugged and may be used in relatively rough terrain. The machine may pass over rocks, small shrubs, brush, as well as furrows and other irregularities without damaging the seeding mechanism. (3) By its action in forming small corrugations and packing the soil, it prepares a seedbed as well as plants the seed. (4) Since it places most of the seed in favorable position for germination, less seed per acre is needed than in some other seeding methods such as broadcasting.

The machine may be used for seeding single species as well as combinations of species. While clean seed of several species of approximately the same size may be used in a hopper, closer control of rate of seeding may be secured by using a single species in each hopper. It also appears desirable to seed species separately rather than in mixtures, since the most aggressive species do not then compete unduly with weaker ones during the seedling stage. Since different species may be used in each of the four hoppers, the effect of a mixture may be secured, as the plants established will be growing in close proximity.—E. L. BEUTNER *and* DARWIN ANDERSON, *Division of Research, Soil Conservation Service, cooperating with the Arizona Agricultural Experiment Station, Tucson, Ariz.*

COLCHICINE-INDUCED POLYPLOIDS IN WHITE CLOVER

RECENTLY, the hypothesis was presented that the genus *Trifolium* includes species in which chromosome doubling might be expected to yield results of practical importance.[1] In view of this concept, certain results with *Trifolium repens* (2n = 32) may be of interest.

In 1937, seedlings of the Kent strain of white clover were treated with 2, 4, or 8 drops of 0.1, 0.2, or 0.4% colchicine solution by placing the drops at hourly intervals on the meristem between the cotyledons at a stage when the unifoliolate leaf was unfolding. Each treatment produced abnormal appearing plants, but the most severe treatments were the most satisfactory since with them the abnormalities were most conspicuous and they were produced in highest percentage.

When the treated plants were 6 months old and each had produced several stolons extending beyond the edge of the 4-inch pot in which it was growing, 10 cuttings from as many separate stolons were removed from each of 20 of the most abnormal appearing plants. Cuttings of white clover give rise to numerous adventitious roots, which can be examined easily for a cytological appraisal of chromosome number in the parent stem tissue. Root tips from some of these cuttings proved to be mixoploid, and some of the plants grew poorly in the greenhouse. Consequently, 10 of the plants were selected because they were the most vigorous and because they contained only 32-chromosome and 64-chromosome but not mixoploid tissue.

Cytological examination had shown that among the 10 cuttings made from each of the selected plants, the number with doubled chromosomes (64) ranged from one to eight. When the mixoploids had been eliminated, the 32- and 64-chromosome pieces generally could be distinguished macroscopically by the larger size of leaves, stolons, flower parts, and seeds on the 64-chromosome sectors. The 10 cuttings from each of these selected plants were increased vegetatively for three replicated plantings in the field.

After the slips in the field had reached a mature growth stage in their second summer, the relative vigor of each cutting was noted, based on a scale of 1 for the least vigorous and 10 for the most vigorous. Analysis of variance for these data (Table 1) showed highly

TABLE 1.—*Analysis of variance for relative vigor, during their second summer in the field, of 10 pairs of 32- and 64-chromosome cuttings, each pair derived from a single seedling of Trifolium repens.*

Source	D.F.	Mean square	F
Chromosome numbers	1	222.7	300.89**
Plants	9	5.9	7.99**
Replications	2	0.9	1.24
Chrom. No. × plants	9	4.9	6.65**
Error	38	0.7	—
Total	59		

**Exceeds F for P = .01.

[1]LEVAN, A. Plant breeding by induction of polyploidy and some results in clover. Hereditas, 28:245–246. 1942.

significant differences for chromosome numbers, plants, and the interaction of chromosome numbers × plants.

The 32-chromosome cuttings averaged 8.38, whereas the 64-chromosome pieces averaged only 4.53. This greater vigor for the 32-chromosome cuttings held for all 10 selected plants, and the differences were significant for 9 of the 10 plants. Since the 64-chromosome sectors always appeared to have a slower growth rate, their practical agronomic usefulness for forage seems to be limited. Present cytological and genetical evidence indicates that 32-chromosome white clover is an allotetraploid, so that doubling to 64 chromosomes may exceed the optimum number for the species.

Some of these 32- and 64-chromosome pairs of cuttings have been used further in studies of the behavior of their oppositional alleles.[2]—SANFORD S. ATWOOD, *U. S. Regional Pasture Research Laboratory, State College, Pa.*

---

[2]ATWOOD, S. S. The behavior of oppositional alleles in polyploids. Submitted to Proc. Nat. Acad. Sci.

AGRONOMIC AFFAIRS

DR. JAMES McKEEN CATTELL

Doctor J. McKeen Cattell, editor of *Science*, died on January 20, 1944, at the age of 83.

Doctor Cattell served science and scientists in many important ways throughout a long and active life. Although better known to scientists generally for his editorial connections with *Science*, *American Men of Science*, *The Scientific Monthly*, and other publications, he first acquired distinction in the field of psychology, holding the first chair of psychology in any university when he accepted an appointment as lecturer in psychology in 1887 from the University of Pennsylvania. In 1891, he accepted a call from Columbia University where he established the department of psychology and was head, also, of the work in anthropology and philosophy.

Long active in the American Association for the Advancement of Science, Doctor Cattell was president in 1924 and has long been identified with the executive committee.

In 1895, Doctor Cattell acquired the weekly journal *Science* which was established in 1883 by Alexander Graham Bell and since then has been its editor and publisher. *Science* has been the official journal of the American Association for the Advancement of Science since 1900. In 1900, he acquired *The Popular Science Monthly* and changed the title to *The Scientific Monthly*. In 1906, he published the first of a series of the Biographical Directory of American Men of Science. These and other publications are now printed by the Science Press Printing Company, which Doctor Cattell established in 1923.

NEWS ITEMS

According to *Science*, the Hebrew University of Jerusalem will graduate this year the first class of agronomists to be trained in Palestine. As recently as five years ago it was necessary for students who wanted professional training in scientific agriculture to go abroad. The Hebrew University, in cooperation with the Agricultural Research Station of the Jewish Agency, now provides a School of Agriculture of university rank. The head both of the School of Agriculture and of the Agricultural Research Station is Professor I. Elazari Volcani. The School provides a five-year curriculum. The first two years are devoted to the study of the natural sciences and are followed by one year of practical farm work. The fourth and fifth years include practical as well as theoretical instruction in farm management, soil science, field and garden crops, horticulture, citriculture, agricultural entomology, plant pathology, and animal husbandry.

—A—

H. C. Porter, Assistant Agronomist assigned to soil survey work in Virginia, was inducted into the armed forces on December 23 last. At the time of his induction Mr. Porter was senior field man of the soil survey work in that state.

THE AMERICAN SOCIETY OF SUGAR BEET TECHNOLOGISTS held an Eastern Slope and Intermountain Regional meeting in Denver, Colo., on February 1, 2, and 3, with sectional programs on the processing and treatment of sugar beet seed, mechanization in relation to sugar beet production, agronomic problems, labor, and sugar beet improvement. The papers are to be made available in mimeographed form. H. E. Brewbaker of the Great Western Sugar Company, Longmont, Colo., was chairman of the program committee.

—A—

IN THE MEMORIAL statement on Harvey Leroy Westover on page 1056 of the December, 1943, number of this JOURNAL, the date of Mr. Westover's birth is erroneously stated to have been June 4, 1887. The correct date is June 4, 1879.

—A—

IN A RECENT number of *Science* it was noted that on December 20th last, a collection of 120 letters from professional associates and friends from all over the country were bound and presented to Doctor Oswald Schreiner in recognition of his 40 years of service in the U. S. Dept. of Agriculture. Doctor Schreiner joined the Bureau of Soils in 1903 and later became chief of investigations in soil fertility, retiring on December 31, 1943.

—A—

THE WAR MANPOWER COMMISSION, Bureau of Placement, has prepared a description of the profession of Agronomy which may prove useful to those confronted with question pertaining to the draft status of members of their staff. Requests for copies of the statement should be addressed to Leonard Carmichael, Director of the National Roster of Scientific and Specialized Personnel, Washington, D. C.

—A—

THE PROCEEDINGS of the second annual meeting of the National Joint Committee on Nitrogen Utilization held in Cincinnati, Ohio, November 9, 1943, has been published by the National Fertilizer Association, Washington, D. C. Dr. F. W. Parker was elected general chairman of the Joint Committee; Dr. N. J. Volk, vice chairman; and H. R. Smalley, secretary. Participating organizations included the Association of Land-Grant Colleges and Universities, American Society of Agronomy, American Society of Horticultural Science, National Fertilizer Association, Tennessee Valley Authority, U. S. Dept. of Agriculture, and the Society of American Foresters. A statement of policy regarding the use of chemical nitrogen in various farming systems and reports of the several subcommittees are included in the proceedings, now available upon request to the National Fertilizer Association, Investment Building, Washington, D. C.

JOURNAL
OF THE
American Society of Agronomy

VOL. 36 MARCH, 1944 NO. 3

STREAMLINING PROJECTS TO MEET CURRENT PROBLEMS[1]

W. V. LAMBERT[2]

WAR brings crises in the affairs of men and nations and these crises in turn bring a multitude of new problems. While these problems may be similar to those of peace-time, they usually have an urgency about them that demands rapid solution. Of this fact I am sure no one is more aware than are the members of this Society. The increased food production demanded of American farmers has forced agronomists and others to dig deeply into the storeroom of facts, and to marshall these facts and make them available in a manner that will assist farmers in meeting the tremendous goals required of them.

Periods like the present force institutions to examine their programs in the light of past accomplishments, and to ask themselves how their programs can be made more effective. Crises, to some extent, illumine the weak as well as the strong points of a research program. They highlight the activities which have been productive and force more careful scrutiny of projects in general. And they emphasize the necessity for organizing research in a manner that will get the most rapid solution of important problems.

The basic problem in organization of research should be to get the answers to problems quickly and at least cost. Any system that does this is a good one. The task assigned to me today is to tell you what, in my judgment, are some of the elements of such organization, and how we can, perhaps, change our activities to make them more useful in meeting the war effort. Since a good pattern of organization to meet the problems of war has so many of the characteristics of an effective pattern for peace-time, I am going to discuss, first, the over-all problem of organizing research in the experiment stations.

FACTORS IN ORGANIZATION OF RESEARCH IN EXPERIMENT STATIONS

The essential steps in the organization of a research program are relatively simple. They consist in (1) selection of the important

[1]Presented before the general meeting of the American Society of Agronomy in Cincinnati, Ohio, November 11, 1943.

[2]Associate Director, Purdue University Agricultural Experiment Station, Lafayette, Ind.

problems; (2) in outlining these problems in a way that will give priority of research on the most essential phases; (3) in breaking the problem down into its component parts so that these can be assigned to qualified specialists; (4) in coordinating the activities of the specialists so as to keep the program fluid and the energies of the staff focused on the important phases; and (5) in obtaining the necessary cooperation with other agencies on important regional or national problems.

The choice of problems, obviously, will be determined to a considerable extent by the location of the experiment station. However, of the many problems confronting any station, some are more important than others and because of budgetary limitations, relatively few of them can be investigated. Consequently, the choice of problems is critical, for largely upon these choices will depend the progress of agriculture in an area; and from the standpoint of the station, its ability to continue to merit the support of the public.

While there likely is no best method for determining the relative importance of problems, I am certain that the best thought of all groups that may be involved in their solution is needed. This means considerable planning and forethought in the selection of problems and in fairly frequent revision of plans to keep the research abreast of changing conditions. One effective method for this purpose consists in having each department develop a long-range program, and where this program impinges upon the activities of other departments, to ask staff members from those departments to assist in formulating the program. Another scheme that should prove helpful is the establishment of station advisory groups whose function will be to confer occasionally with the specialists in a given field of work. Such groups probably can be most helpful by making suggestions after a tentative program is developed. If well chosen, such groups also furnish fine points of contact for selling the program in the state and in obtaining support for the station.

After certain problems have been selected for investigation, it becomes essential to set up a plan of attack on these problems. In this process, the important consideration is to get the answer to the problems most quickly and at least cost. Since most problems cut across departmental lines and because the staff in most stations is organized on a departmental basis, it becomes necessary to devise ways and means to use the staff needed to complete the job most effectively. To accomplish this, it may be necessary to organize any major line of research as a station program or master research project which outlines the broad objectives of the program, delineates the scope of activities, and sets forth the necessary pattern of cooperation. Specific activities of this program may then be developed as sub-projects which can be undertaken in sequence as dictated by priority and by the staff members best qualified to handle them.

It may be argued that such a plan will tend to disrupt organization and destroy individual initiative. This need not be true if the program is well organized and efficiently administered. In fact, it should, and I believe does, prove stimulating to most staff members, for it ties them into the major problems of the station and tends to give

broad direction to their research. The essential steps to be guarded in such a plan of organization are to break the problem down into discrete units, to assign these jobs to individuals or groups for solution, and to put in charge of the program an aggressive, inspiring, generous and cooperative leader.

Regardless of the plan of organization that is followed, any program is apt to become more or less static. Consequently, it is the task of administrators to require fairly frequent reviews of the project structure of the station. This tends to keep the program fluid and abreast of the problems confronting a rapidly changing agriculture. Few projects, in my judgment, should be approved for a term longer than five years, and but few for that long. This does not mean that productive activities may not be continued for longer periods, but merely that each researcher must take occasional inventory of his activities and reorient them in the light of accomplishments. Most experiment station research is supported by public funds and the continued support of research likely will be based largely upon the dollars and cents value accruing from it. Frequently, I find folks who are apparently unconscious that over a period of 5 to 10 years, the public has invested a sum of 50 to 100 thousand dollars, or more, in their work and sometimes without much to show for it. While it is inherent in the nature of research that not all of it can be productive, every research man has an obligation to make it as productive as possible. I do not mean that every piece of research should be of immediate practical value. However, it should be aimed at, and if need be, integrated in a program that has as its objective the solution of certain specific problems of society. This broad basic purpose of research should serve as a challenge to each research worker for more effective organization and prosecution of his work.

One of the important developments in research in recent years is the ever-growing pattern of research between the experiment stations and between the stations and the U. S. Dept. of Agriculture. Perhaps the best known example of such cooperation, and the most effective as measured by accomplishments, is that concerned with the development of hybrid corn. In this work, the Department and the stations have set a high standard and one that will reflect to their everlasting credit. More recently, much progress has been made in other areas such as soil conservation, the breeding and testing of cereal crops, and many others. This, in my judgment, is one of the most promising developments of research in the field of agriculture. So many of the problems of agriculture transcend state lines that a regional or national approach toward their solution is the only logical and hopeful one. If existing organizations don't, solve them, it is probable that new agencies will be created for this purpose. The directors of the experiment stations of the north-central region within the past several years have initiated cooperative work on a number of important problems affecting Corn Belt agriculture. Much progress has been made, but better patterns for cooperation are needed. These should make provision for cooperation with any institution or organization that can contribute toward the solution of problems. The best and newest findings and technics from the basic sciences must

be brought to bear on the problems of agriculture. That such patterns will develop out of further experience in this direction, I am certain.

ORGANIZATION OF PROJECTS TO MEET CURRENT NEEDS

The realignments and reorganizations made necessary by war enlarge old problems and create new ones. Certain of these may have lasting effects upon the pattern of agricultural research. It is to these problems that I shall devote the remainder of my discussion.

One of the first steps in streamlining a station program to meet current needs should, in my judgment, be to marshall existing facts and to make these available to farmers and others to whom they may be useful. In fact, the unavoidable slowness of research may decree that the major contributions of the experiment stations in the war effort will be the marshalling and publishing of facts obtained from past research. This has been widely recognized and the experiment stations have contributed very effectively in this respect. Perhaps this activity should receive more attention as a permanent part of their programs. At least every station should give additional consideration to developing more effective means for getting the findings from research more quickly and widely into use by farmers, and others.

A second step in the organization of a station program to meet current problems should be the careful scrutiny of existing projects. All projects which have proceeded to the point where the results may contribute to the war effort should be summarized and the results published; and pertinent data, even from those projects only partially completed, should be released. Similarly, new crop varieties which normally would be withheld for further study or testing should be released if, by their release, the war effort will be served.

By following this plan, the station will receive more credit for the contribution than if the results were held until after the war, and, more important, agriculture should be in a better position to meet the tremendous goals now required of it. Where additional information on a subject is required, the possibilities of completing projects concerned with such problems in a shorter time should be explored. With new and promising varieties of crops, this might be accomplished by increasing the number of test plantings. In the case of pasture or nutrition experiments, more and better designed trials might be conducted for getting quick answers to critical feed problems. In many cases, such schemes might be employed to get new facts or results in a minimum of time. It is in this area that the stations can perhaps contribute most in meeting the problems that confront agriculture in the immediate future.

As the third step in reorienting a station program to meet current problems, I believe more than usual scrutiny should be given to all new projects. In general, such projects should have a direct bearing on the war effort. While every project perhaps cannot have direct application to the emergency, this principle should be adhered to as closely as possible. In common with every organization, our main concern now is to win the war and we must devote our energies wholeheartedly to this task. This may mean rather drastic reorganization,

even requiring the transfer of staff members to other than their usual lines of activity. Fortunately, most workers are willing and anxious to make their efforts most useful in the emergency, and will welcome suggestions to this effect if they are shown that this will promote the war effort. In such cases, only personnel qualified by training should be so transferred.

In certain cases, the organization of research teams for work on important problems may be an effective approach to the rapid solution of problems. This type of organization should bring to bear upon the problem the talents of any staff member who might contribute to its solution. Such organization will tend to avoid the restrictions of departmental organization and to concentrate the efforts of the staff most effectively upon the solution of major problems. Some problems lend themselves more directly to this approach than others, but there are few cases where it cannot be effectively employed at least to some degree. This is a type of organization frequently employed by industry and is one that might, I believe, be effectively employed more frequently in experiment stations.

Where this method is used, the director must be sure that the project is organized in such a way that the development of initiative on the part of the individual worker is encouraged and that proper recognition is given to the contributions of each worker. If these points are not guarded zealously, this method of solution of problems is doomed to failure.

FUNDAMENTAL RESEARCH MUST NOT BE NEGLECTED

In his desire to streamline the station program, and in the zeal of his staff to contribute most to the war effort, the director must guard against the dropping of important fundamental research projects. The long-time direction of the research program of the station must be given consideration. In the long run, it is fundamental research that creates the stockpile of knowledge essential for progress and the meeting of unforeseem emergencies. The ability of agriculture to meet the tremendous goals now required of it is unquestionably due in large part to the fact that research in the experiment stations, the U. S. Dept. of Agriculture, and elsewhere, has established the necessary facts and techniques and created new and better crops and animals. We must not overlook this point, and we must ever keep this function of research agencies alive in the public consciousness, even though the energies of such agencies must be largely and rightly directed toward the solution of more immediate problems during the war.

If it is decided that an important long-time project will contribute little to the war effort and it can be shelved for the duration without loss of necessary continuity, this should be done, especially where the personnel involved in such projects can be used effectively upon more critical jobs. By this process, the director should be able to compensate in part for the loss of personnel, and, at the same time, be able to hasten the completion of projects which may contribute to the solution of urgent problems.

In closing, I wish to emphasize that I am fully conscious of the limitations of these suggestions, and of the difficulty in following through with them. Nevertheless, the experiment stations and other research agencies must contribute to the solution of urgent problems created by the war if they are to continue to merit the respect and support of the public. Fortunately, the benefits to be achieved by a good streamlining program transcend the present emergency. The pattern of organization established now likely will serve to guide programs in the post-war period when the problems of agriculture, while perhaps somewhat different, certainly are not apt to be less urgent. Here, as in other areas, there would seem to be opportunity and perhaps need for research. With the possibility of curtailed budgets and increased demands for service confronting us in the post-war world, we must be ingenious in employing all possible methods in making our programs effective. And scientific men must accept the challenge to keep the creative energies of research focused most effectively upon the urgent problems of mankind. The burden of discovery of new facts rests largely upon their shoulders and they must play an increasingly important role in getting these facts utilized for the promotion of the best interests of the nation and the world. Upon their ability to do this, I believe, hinges much of the direction of man's progress toward a higher and better type of civilization.

SEED CERTIFICATION IN THE UNITED STATES AND CANADA[1]

E. F. Frolik and R. D. Lewis[2]

TODAY, as agricultural scientists look in retrospect upon their work to see what they have accomplished that is of value to the war effort, they can justifiably focus their attention upon a particularly significant contribution—seed certification. For, as a part of the broad program of the plant breeder, seed certification is helping to accomplish the purpose for which it was initiated, the improvement of the major and many of the minor crop varieties grown on American farms.

WHAT IS SEED CERTIFICATION?

Certified seed is generally recognized to be seed of known superior heredity and quality verified by and traceable through the periodic inspection and records of an impartial and officially recognized agency. It is the "known superior heredity" factor that chiefly distinguishes certified from other types of seed. Seed certification sponsors and identifies a product which is superior not only in physical characteristics but fundamentally in the germ plasm of the seed.

Were it not for this highly significant factor of known heredity, there would be little, if any, justification for programs of seed certification. For the purpose of ordinary protection there are in operation state and federal laws and regulations in the United States and Canada covering the sale, testing and labeling of farm seeds. These laws and regulations safeguard the buyer to a considerable extent, especially if he is sufficiently interested to avail himself of the assistance provided. Hence, from the standpoint of mechanical purity and quality, present seed regulations take care of the situation fairly well.

Mere laws and regulations, however, do not help the farmer much in securing the inheritance he requires of the seed he is buying. One cannot determine through analysis the true production potentialities of seed and, for the most part, varieties cannot be distinguished by seed characteristics. Inspection of the growing seed crop sheds considerably more light on varietal identification and purity than does mere examination of the seed. Even field inspection may not be adequate. Some varieties are not easily distinguished from other varieties in any stage of development. An example of this is the newly-developed wilt-resistant Ranger alfalfa. On the basis of morphologic characteristics, it cannot be distinguished in the field from several other varieties. Therefore, to be certain of the identity of Ranger alfalfa, seed and field inspection must be combined with carefully kept records which refer any lot of certified seed to the original stocks of the plant breeder.

---

[1]Contribution from the Department of Agronomy, University of Nebraska, Lincoln, Nebr., and Department of Agronomy, Ohio State University, Columbus, Ohio. Presented by the senior author as part of the general program of the annual meeting of the Society at Cincinnati, Ohio, November 11, 1943.

[2]Assistant Extension Agronomist, University of Nebraska; and Chairman, Department of Agronomy, Ohio State University, respectively.

EXTENT AND IMPORTANCE OF SEED CERTIFICATION

Seed certification is being conducted in 40 states of this country and in the Dominion of Canada. It deals with the seed or vegetative reproductive parts of approximately 25 crops and 500 varieties (not including corn hybrids).

As pointed out by Lewis (6),[3] well-organized seed certification work in the United States is largely a development of the past 25 years. During this period there has been a steady growth in both the quality of work involved and in the extent to which American farmers have availed themselves of this service. The growth has been accelerated during the past decade and especially so during the late 1930's and early 1940's. Fisher (3, 4) reports that there were produced in the United States in 1939 15 million bushels of certified seed and tubers (exclusive of tobacco and most vegetables). By 1940 this figure had risen to approximately 20 million bushels and by 1942 to approximately 31 million bushels—an increase within a period of three years of 107%. From indications of 1943 the volume of certified seed produced is still growing at a rapid rate.

The crops certified include the grain, forage, fibre, oil, and vegetable crops; in fact, seed certification embraces all crops of appreciable economic value being grown in the United States today.

ORGANIZATION

Although seed certification practices in the United States and Canada are in many respects conducted similarly, there is one important difference. In Canada the work is done on a national basis and under the sponsorship of the Dominion government. In the United States the work is organized at a state level with no direct financial support or control by the federal government. In most states this work is handled by associations composed of seed growers and with elected boards of directors.

Agronomists employed by state agricultural colleges and working with seed certification are invariably of the opinion that seed certification should remain on a state basis. They have had the full and unselfish cooperation of agronomists of the U. S. Department of Agriculture in their work. From a national standpoint, M. A. McCall, O. S. Aamodt, M. A. Hein, E. A. Hollowell, and H. M. Tysdal of the Bureau of Plant Industry, Soils, and Agricultural Engineering; O. S. Fisher of the Extension Service; M. M. Hoover of the Soil Conservation Service; and W. A. Davidson of the Agricultural Marketing Service have been especially constructive in counselling and advising as to opportunities and procedures that give greater strength and meaning to present seed certification programs.

The democratic set-up in seed certification has been emphasized. Equally important in these programs are the counsels of agronomists. That this point has been appreciated by the seed growers is evident through the fact that according to unpublished data by Clapp and others (2) in 35 of the 40 states where seed certification obtains, there

[3]Figures in parenthesis refer to "Literature Cited", p. 192.

is a direct working relationship with agronomists of the respective state agricultural colleges.

In 27 of these 35 agencies the cooperative set-up is with the state agricultural college while in the remaining eight the cooperation is with both the state agricultural college and the state department of agriculture. The majority of the certifying agencies have their offices on the campuses of the agricultural colleges, and generally the extension agronomist or one of the other members of the department of agronomy serves as the executive secretary of the organization. This staff man is usually elected by the seed growers; he is responsible chiefly, insofar as seed inspection and certification work is concerned, to the board of directors of the organization he is representing.

Almost without exception these certifying organizations assess inspection fees to finance their programs. In most cases, however, there is some subsidization of the programs. Although a direct legislative appropriation for seed certification work is made in only nine states, financial support is given in most states through the furnishing of office space by the agricultural colleges, through regular staff men devoting part of their time to seed certification work and through other indirect methods. As volumes of certified seed increase more of the total expense comes to be borne by the seed growers, and frequently one or more additional full-time employees are financed from fees paid by the growers. There appears, however, to be no desire in most states to divorce seed certification work from its close working relationship with the agricultural colleges.

THE INTERNATIONAL CROP IMPROVEMENT ASSOCIATION

Thirty-five of the seed certifying agencies in the United States and Canada are organized into the International Crop Improvement Association. The purpose of this organization as stated in the constitution is "...........directed toward attaining one major object—the permanent improvement of crop quality and yield and the encouragement of farm use of such improved field, garden vegetable, and root crops.........."

The meeting leading to the organization of the International Crop Improvement Association was held in July, 1919. Very early in its history the Association set forth as one of its primary functions, "Assisting in the standardization of the seed improvement and certification work being done by member organizations."

Through the years there has been an ever-increasing emphasis placed on this objective. The first attempts to carry it out were made through committee action. The men on these committees did as much work as possible through correspondence, held brief meetings and submitted their reports at the annual meetings of the organization. Some progress was made but much was left to be done.

Some years ago, a few far-sighted directors of the International Crop Improvement Association began to see that the solution to standardization of certification rules and procedures lay in learning more about the problems involved. The idea of studying some of the

basic principles concerning seed certification grew rapidly. In 1940 an International committee, with Lewis of Ohio as chairman, reported (8) the need for a "study of the systems of inspection, certification, and registration of field seeds by state agencies and their relation to the interstate shipments of seed subject to the Federal Seed Act". At the annual meeting in 1942 a committee appointed by President Mercer of Montana, with Clapp of Kansas as chairman, submitted specific plans for making a summary study of seed certification as it is now being conducted in the United States and Canada. The plan was accepted. Since the financial resources of the member state organizations vary a great deal, it was decided to raise the necessary funds to carry on the work through voluntary contributions. Sufficient money was raised in this way to finance the plan of operation.

This initial study conducted in 1943 is a mere beginning to those needed to be made in connection with the principles of better seed production. It may be likened to a reconnaissance in that it consists of summaries of the seed certification standards and procedures now in operation in the United States and Canada but does not delve very deeply into the basic principles involved. The findings are primarily for use as reference material by members of the International Crop Improvement Association. Heretofore, the Association committees responsible for formulating the recommended certification standards and procedures for various crops have not had the benefit of a thorough-going study of certification standards to guide them in their work. Now, taking into account what is actually being done by the different certifying agencies with respect to the problem at hand, they are in a far better position to set up uniform minimum standards to be followed by all those certifying agencies. This was done for a large number of seed crops at the last annual meeting of the International Crop Improvement Association in Chicago, November 28 to December 2, 1943.

Looking to the future, it is hoped that all member certifying agencies will adopt the minimum standards set by the International Crop Improvement Association so that certification will come to have understandable interstate significance. These individual certifying agencies will, of course, be free to impose as many additional restrictions as they wish.

The various certifying agencies have need of reasonable uniformity in their certification standards because there is a considerable movement of seed across state and national lines. Farmers buying certified seed from out of the state often apply for certification in their own state of the crop raised from such seed. Clapp (2) shows that 25 out of 31 states accept certified seed from other states as a source of further certification in their programs. It follows that these states should know something of this material which they are willing apparently to accept for use in their own programs.

THE AGRONOMIST HAS A VITAL INTEREST IN SEED CERTIFICATION WORK

The agricultural research worker, whose services and activities are made possible through public funds, has as his first obligation the

well-being of the American farmer. Searching for improvement in agricultural practices and materials is the province of most research agronomists. A corollary is that once an agricultural scientist has developed an improved practice or an improved strain or hybrid, he has a vital interest—yes, he has a moral if not an actual obligation in seeking to gain public acceptance of his contribution.

The fact that this obligation is recognized helps account for extension services being an integral part of our agricultural colleges today. While there is reliance upon the extension service as a medium for distribution of agricultural developments, it, too, is limited in its scope of operations. It is primarily an educational agency. And education is not enough in this matter of increasing, maintaining, and distributing good seed. The extension service can preach the gospel of good seed with fervor and energy but what the extension service needs to tell the farmer is the answer to what the farmer wants to know: "Where can I get this type of seed?" The seed certification service is the answer by virtue of that much needed service which it supplies, namely, getting the good seed increased under reasonable controls in order to make it easily available and at the same time to guarantee its identity to farmers.

A. B. Graham, formerly of the U. S. Department of Agriculture Extension Service, often said with respect to getting a practice adopted, "Make it easy to do". Seed certification makes it easy for the farmer to plant seed of improved strains, varieties, hybrids or composites.

WHAT THE CERTIFYING AGENCY CAN DO FOR THE AGRICULTURAL EXPERIMENT STATIONS

The first and most obvious service that the certifying agency can perform for the research agronomists is that of increasing the supply of pure seed of improved varieties. These new varieties, no matter how superior, need much nurturing in their early stages. And even after they have become rather widely distributed and accepted, there continues to be need for sources of pure seed. Without a seed certification service, varieties tend to become mixed, contaminated and confused as to identity. If the highest yielding varieties maintained their relative proportion in mixed populations, there would be less concern about admixtures than there now is. However, as stated by Suneson and Wiebe (10), "The relative yield of a variety is not necessarily a criterion of its ability to survive in competition with other varieties grown in mixtures in the same locality."

Often varietal identity becomes obliterated. For example, LeDioyt (5) in a survey in Nebraska in 1939 showed that 73.5% of the wheat being grown was undesirable as a source of seed largely because of mixtures and, furthermore, that 32.6% of the farmers were incorrectly naming the varieties they were growing.

Secondly, the certifying agency through its membership provides the agricultural scientists with a receptive and informed group of farmers willing to cooperate in the application of new agricultural practices. In addition to conducting extensive tests prior to the time

a variety is released or a practice propounded, most agronomists wish to subject their developments to a restricted group of farmers for observation under a wider range of conditions than is possible in formal testing programs. The certified seed growers, well informed and understanding of the experiment station problems because of their close connection with it, are willing to try these new developments on a limited scale. They are qualified, moreover, to give intelligent reports on their observations. From these "pilot-plant" trials it is relatively easy to go either in the direction of general recommendation or in the direction of withdrawing or at least limiting the proposed recommendation, depending upon the results attained.

The research agronomist can and is going one step further in his utilization of the services of the certified seed growers. With the assistance of these farmers he can get seed of a new variety increased before it has been tested sufficiently to justify certification, in fact, even before he is sure whether or not the variety should ever be named and released. The advantages of such a system are obvious. It speeds up by several years the availability of promising plant material. Seed increase and testing can be carried on simultaneously. If, at the end of what is considered a sufficiently-long testing period, the decision is against release, the seed increase is disposed of as commercial seed without benefit of varietal identification or, better yet and more frequently, as feed, food, or fibre.

Ranger alfalfa is an example of a crop which was increased in this way. Seed increase by farmers and extensive testing were started at about the same time. Experienced seed growers were given small amounts of seed to increase. They signed an agreement to the effect that their respective certifying agencies and agricultural experiment stations had full authority to designate the disposal of any seed produced by them during a period of 5 years. The growers further agreed that if the variety was not ultimately recommended for certification, they would dispose of the seed through regular commercial channels without making any claims of superiority. Now that Ranger has been accepted as a superior variety, all of the seed that these growers are able to produce is in extremely high demand. Even though seed supplies of Ranger are still inadequate, a much smaller quantity would be available today had the alfalfa breeders and certification workers not had the foresight to initiate a parallel, cooperative, and mutually understood program of varietal testing and seed increase when Ranger first emerged as a promising variety. A similar but less time consuming program has been used in 1942 and 1943 in increasing seed supplies of the new Lincoln soybean in Iowa, Illinois, Indiana and Ohio.

WHAT THE RESEARCH AGRONOMIST CAN DO FOR THE CERTIFYING AGENCY

The research agronomists can render many services to the certifying agencies. First, improved varieties furnished through the efforts of the plant breeder are obviously the "life blood" of the certifying agency's program. Without detracting from the principle that the

plant breeder's chief function is developing improved varieties for all farmers, it can also be said that new and improved varieties are important to the success of the seed grower's business. For him as for the automobile dealer, new "models" expedite sales.

Second, the agronomist in addition to his breeding program, tests varieties released elsewhere with respect to local adaptation. The aforementioned certification study (2) shows that of the 22 states answering this question, none approves varieties for certification without data from agricultural experiment station tests. It is interesting to note that certifying agencies vary with respect to the exact authority delegated to the experiment station on determining the eligibility for certification. In 11 of the 29 states answering this question, the experiment station has full authority in this matter, in 7 states the matter is entirely in the hands of the certifying agency, and in the remaining 11 states the matter is handled cooperatively.

This interdependency of the two agencies in the certification program requires a close working relationship and complete understanding of all workers over broad geographic areas. If the certifying agency relies upon the experiment station for approval of varieties, then the experiment station worker must be familiar with the situation not only in his state or province but also in adjacent and often distant states. Seed of a variety may be grown in one state or province because of favorable seed-producing conditions there, for utilization in another state or province. Foundation seed of Cumberland red clover is produced in Kentucky, Tennessee, and Virginia, sent to the western states for increase, and the increase shipped back to the Southern Cornbelt and Northern Cottonbelt states for commercial clover production. Unpublished data by Hollowell show that red clover grown for successive generations in the western states tends to lose some of the disease resistance so important in the eastern states. For this reason, the foundation stocks must be maintained in the indicated eastern states and periodically furnished to the western growers. The details of this program are being carried out largely by the certifying agencies but the scientific information itself is developed and furnished by research agronomists.

The third way in which the research agronomist can assist the certifying agency is through research that provides fundamental information required for setting up the certification procedures and standards. As suggested earlier, there are many principles with respect to good seed production methods which remain to be worked out. This field in itself offers innumerable opportunities for further research work in agronomy. Already agronomic literature contains numerous reports dealing with various types of investigations which offer the certification worker excellent assistance in drawing up standards and in carrying on his work.

One example of such a report is the recent work of Schwendiman and Shands (9) at the Wisconsin Agricultural Experiment Station on seed dormancy in Vicland oats. They report, "In the fall of 1940 several instances of delayed germination were noted in freshly harvested samples of Vicland oats . . . . As this variety was about to be released for commercial production it seemed important to

determine the extent and nature of the delayed germination. The immediate need for such a study was occasioned by the necessity of establishing a satisfactory testing procedure for making germination tests in order to judge freshly harvested seed as to requirements for certification."

They found that ". . . a rapid and satisfactory test was secured by pre-chilling the moistened seed for 4 days at 4 degrees Centigrade and then placing it at 22 degrees Centigrade for 6 days." The results of an experiment such as this are most useful to the successful conduct of a seed certification program.

In addition, the research agronomist can offer excellent counsel in organizing and stating certification standards. Admittedly there are many points which must be covered in certification standards concerning which experimental data are inadequate. But, even in these instances, the opinions of well-informed agronomists are far better than the guesses of non-technical men.

Fourth, the agronomists are in an excellent position to train and approve inspectors for seed certification work. Ideally, at least, these inspectors, exercising a minimum of police power, should be technicians capable of counselling with the seed grower in good seed production methods. A complicating factor in securing qualified inspectors is that the inspection work in general is seasonal. For this reason it is impossible to employ full-time trained agronomists to do all of the work. A not-uncommon practice among certifying agencies is to hire Smith-Hughes and other high school instructors to do field inspection work during the summer months. Rarely do these part-time employees have a thorough training in agronomy. Many of the certifying agencies bring these men together for concentrated training in the methods of inspection and in ways of providing service, counsel and guidance to the seed growers. Like the army teaching methods we are hearing so much about these days, these concentrated, streamlined short courses are doing much to prepare the inspectors in the necessary fundamentals of production and processing of certified seeds.

The more training the inspectors can get in their immediate problem of inspection and in related agricultural subjects, the more service they can perform and the more readily they will be accepted by the seed growers. To the farmer, removed geographically as he usually is from the experiment station, this inspector is the connecting link with the ideas and techniques developed at the experiment station. The seed grower may want to discuss such related problems as weed control, diseases, and soil fertility. The inspector who is capable only of telling whether or not there is any varietal mixture in the crop at hand may make out an acceptable inspection report but he may also leave the farmer dissatisfied with the service.

Lastly, the research workers can be of assistance in supplying foundation seed or assisting in a program through which foundation seed is provided for the certified seed growers. Regardless of how carefully certified seed is handled, there is increasing danger of mixture with each successive generation following release. There is need for periodic purification of seed stocks through methods that may

involve re-selection, hand pollination, and possibly even vegetative reproduction. Subsequently, this seed is carefully increased in sufficient amounts to be distributed to a limited number of growers for further increase as certified seed.

At present, 23 certifying agencies have in their programs provisions for production of foundation seed stocks. In 19 of these 23 the agricultural experiment station is either the source of, or cooperates in, the production and distribution of foundation seed.

The matter of producing foundation seed is a technical job. It involves in the case of sorghums, for example, the bagging of properly selected heads; in the case of corn hybrids, the process of controlled hand-pollinations, and in the case of self-fertilized small grains, the selection of desirable plants, head-rowing these, roguing, and bulking of the suitable selections. Some of the problems in production and maintenance of foundation seed stocks for corn hybrids are presented by Borgeson and Hayes (1) in their report entitled "The Minnesota Method of Seed Increase and Seed Registration for Hybrid Corn". Lewis and Stringfield (7) outline a cooperative method of producing foundation seed stocks.

If definite facilities are not provided for producing foundation seed stocks, this responsibility may prove a real hardship for the already over-burdened research staff and over-taxed physical plant of many experiment stations. It appears that a foundation seed stocks program can be set up satisfactorily in either one of two general ways, as has become especially evident in corn hybrid work where the amount of foundation seed to be produced and the difficulty of producing it are greater than with many other crops.

One method is by means of facilities set up directly by the college of agriculture or experiment station to provide the seed stocks for the cooperating certified growers. Such programs are now being carried out on a large and successful scale in the states of New York, Minnesota and Wisconsin. The other method of providing foundation seed stocks is to set up a corporation supported and, to a large extent, operated by the certified seed growers but with the technical assistance of the agricultural experiment station. A pioneer in this field is Ohio where such an association, the Ohio Hybrid Seed Corn Producers, is doing a significant job of providing seed stocks for the certified seed growers of Ohio (7).

HOW THE SEED GROWER BENEFITS FROM CERTIFICATION

The question may be asked, "Why not furnish foundation seed to successful farmers and let them produce seed without the certification program?" The answer (in addition to the generally-recognized advantages of an impartial inspection service) hinges partially upon the fact that a large part of field seed in the United States and Canada is produced by farmers rather than by specialized seed growers. For a rapidly increasing number of crops, seed production is becoming a complex process. The individual farmer seed-growers do not have the time to become plant breeders or even seed specialists—their business is management of their general farm business.

The result is that they pool their common interests and cooperatively, through the seed certification program, secure advantages, such as the services of seed specialists, that would otherwise and at best accrue only to large, specialized seed producers. In other words, they cooperate in those respects in which there are advantages associated with large-scale operations, and at the same time they retain other advantages which are associated with the relatively small, individual farm business. In one sense of the word, the plant breeders and other agronomists are also a part of this involved program. They, too, are employed on a cooperative basis, the principal difference being that their programs are financed through taxation rather than through an assessment of certification fees.

There seems to be some indication, at least in the case of corn hybrids, that the more thoroughly a breeding program is conducted by the agricultural experiment station and the more comprehensively a certification program is set up and operated on the basis of the publicly-financed breeding program, the greater the tendency is for seed production to be retained in the hands of farmer growers.

The final goal of the certification program is to furnish good seed of superior adapted varieties to the farmer at an equitable price. There can be no justification for a certification program unless it accomplishes this end.

CONCLUSION

In conclusion, we emphasize that seed certification is not a program in or by itself. It is a part of the system of crop improvement, involving the plant breeder, the extension worker, the seed grower, the seed distributor, and the farmer who plants this seed. Seed certification is thoroughly democratic in principle and at the same time scientifically and economically sound. Through it and through other parts of the state and federal agricultural programs, farmer seed-growers receive services, many of which would otherwise be available only to large-scale organizations. The present system tends to keep seed production in the hands of farmer growers. It is a tried and proven program of bringing seed of superior adapted varieties to farmers at equitable prices. Under certification, the maintenance of seed identities of superior strains becomes a matter of democratic control and record throughout all stages of multiplication from the plant breeder to the purchaser and user.

LITERATURE CITED

1. BORGESON, CARL, and HAYES, H. K. The Minnesota method of seed increase and seed registration for hybrid corn. Jour. Amer. Soc. Agron., 33:70–74. 1941.
2. CLAPP, A. L., *et al.* A summary of general rules and procedures of seed certification being used by 34 certifying agencies in the United States and Canada. Int. Crop Imp. Assoc., Spec. Rpt. 1943.
3. FISHER, O. S. Progress report on certifying agencies. Int. Crop Imp. Assoc., Ann. Rpt., 23:54–64. 1941.
4. ————. Report on seed certified in 1942, as reported by state crop improvement associations. U.S.D.A., Mimeo. Rpt. 1943.
5. LEDIOYT, GLENN H. Improving the quality of Nebraska's Grain. Nebr. Grain Imp. Assoc., Fifth Ann. Rpt. of Progress. 1943.

6. LEWIS, R. D. The value of a state seed certification program. Nebr. Crop Growers' Assoc., Ann. Rpt., 32:72–78. 1940.

7. ——— and STRINGFIELD, G. H. Cooperative production of foundation stocks for certified corn hybrids in Ohio. Jour. Amer. Soc. Agron., 30:145–149. 1938.

8. ———, *et al*. Report of the committee on seed marketing studies. Int. Crop Imp. Assoc., Ann. Rpt., 22:89–90. 1940.

9. SCHWENDIMAN, ALVIN, and SHANDS, H. L. Delayed germination or seed dormancy in Vicland oats. Jour. Amer. Soc. Agron., 35:681–688. 1943.

10. SUNESON, C. A., and WIEBE, G. A. Survival of barley and wheat varieties in mixtures. Jour. Amer. Soc. Agron., 34:1052–1056. 1942.

ESTIMATING FORAGE YIELD BY THE DOUBLE-SAMPLING METHOD[1]

H. G. WILM, DAVID F. COSTELLO, AND G. E. KLIPPLE[2]

IN various investigations of the effects of grazing upon forage production and utilization, one of the most difficult problems is an accurate appraisal of the single factor of greatest importance, *viz.*, the volume of forage itself. For a reliable picture of these effects it is necessary to obtain accurate estimates of the actual amount of forage produced or remaining after treatment on each area subjected to experimental control. This task is difficult simply because forage varies considerably in the weight of plant material produced by each species in a highly variable population.

Since all the forage cannot be harvested and weighed, it is necessary to obtain a reasonable estimate of the true total weight by sampling. Using some standard method, such as clipped plots, the sampling procedure is relatively simple in principle. It is only required to clip enough plots, distributed over the pasture by some efficient scheme of randomization, to provide an average forage weight which is accurate within prescribed limits. The number of clipped plots necessary to provide a reliable mean, however, is generally large. Beruldsen and Morgan (1)[3] found that 25 independent observations were a minimum number per sample for acceptable accuracy under their Australian pasture conditions. Davies (4), who also worked in Australia, concluded that the sampling errors of small samples are of considerable magnitude. Ellenberger (5) and his associates in Vermont observed that the weight of forage clipped from small plots varied greatly between pastures and from place to place within pastures. Robinson, Pierre, and Ackerman (7) used nine cages per pasture to protect plots to be clipped and found the sampling errors of the means of these nine observations too large for dependable interpretation of results.

In actual practice, therefore, the sampling process is not an easy task, particularly when field observations have to be taken within a short period of time. Ordinarily, data on forage production, for example, must be obtained within the space of a week or two; and data on residual forage on summer range land must be obtained after the livestock have been removed and before autumn snows make the sampling task impossible.

In experiments on summer ranges we have found it difficult to reconcile these requirements and the limitations of available funds and personnel with the demands imposed by a highly variable population of forage. The number of plots which could be clipped simply did not provide sufficiently reliable information; observed differences among pasture averages could be attributed to little more than the chance variation contained in sampling errors. In such a stalemate we

[1]Contribution from the Rocky Mountain Forest and Range Experiment Station, Forest Service, U. S. Dept. of Agriculture, maintained in cooperation with Colorado State College at Fort Collins, Colo. Received for publication August 11, 1943.

[2]Silviculturist, Forest Ecologist, and Senior Clerk, respectively.

[3]Figures in parenthesis refer to "Literature Cited." p. 203.

have been faced by two alternatives, either to abandon the forage studies or to devise some short-cut method which would provide the necessary information within the prescribed limits of time and funds.

For obvious reasons the second course was chosen, and it then became necessary to select promising short-cut methods and test their efficiency by actual field trial.

A PROPOSED SOLUTION

SHORT-CUT METHODS

After consideration of a number of methods for measuring various factors which might be associated with forage weight, we finally selected two short-cut methods as being the most likely to fit our needs. One, the line-transect, has been used in various fields and was adapted to forage measurements by Canfield (2, 3). The other, which simply involves the estimation of forage weight on sample plots (6), has been tried by a number of investigators.

If used without quantitative control, neither of these methods provides data on forage weight directly, and they are not capable of rigorous test to determine the accuracy of information on forage obtained by their use. By the clipping of forage on some of the estimated plots and in a belt around some of the line transects, however, the data obtained by these short-cut methods could be converted to quantitative weight estimates. Both of the methods seemed to promise considerable reductions in field time requirements, and both appeared simple and easy to apply. And finally, quantitative estimates of the error of forage weights calculated from the field data could be obtained by double-sampling analysis.

DOUBLE-SAMPLING APPLIED TO THE SHORT-CUT METHODS

As the name implies, double-sampling involves the sampling of any population by two methods, one which yields data directly on any desired factor such as forage weight, but is laborious and expensive to use; and another (short-cut) which yields data on some factor which is highly correlated with the desired factor (8) and is much cheaper to use. Use of any short-cut method in the sampling of forage yield causes a loss in precision per plot, as it can provide only an approximation of the actual weight of forage on each plot through a regression of forage weight on the factor observed. Since this method is cheaper to apply in the field, however, so many more sample observations may be taken that a net gain in precision or efficiency may result. The amount of gain, if any, depends on the relative cost of double-sampling as compared to clipping, and on the relative accuracy with which forage weight can be calculated from the regression.

In field forage sampling a number of randomized observations is taken by some short-cut method, and in addition the forage is actually clipped at a relatively small number of sampling points, taken at random from the larger sample. Thus we have available two sets of data, a large sample containing only observations taken by the short-cut method, and, within the large sample, a small sample containing

in addition the actual weights of forage clipped at a portion of the sampling points observed in the large sample.

Then, using only the small-sample data, a regression is calculated to show the relation of actual forage weight (Y) to the factor observed by the short-cut method (X). In itself this regression adds nothing to the information on forage weight provided by the small sample alone. We have also, however, a relatively precise estimate of X, provided by the mean of the large sample (including values for X derived from the small sample); and by solving the regression equation for the large-sample mean of X, a correspondingly more precise estimate of average forage weight may be derived. Also, since both the large and small samples were taken by randomization, an error variance can be calculated for each portion of the regression equation; and thence can be obtained the error of the estimated forage weight.

This method can be substantially refined by segregating the forage into individual species or plant classes (groups of similar species), and making a separate analysis for each. Estimated mean forage weight can be calculated for each plant class from its own regression equation, and the results summed to give the estimated weight of all classes of forage on the pasture. The analytic procedures required for obtaining the regression equations and calculating the error variances of the resulting estimates and of their sums are nicely discussed by Schumacher and Chapman (8, chapters VIII and XI).

As indicated above, the efficiency of double-sampling is affected by the relative cost of clipping as compared to double-sampling, and by the accuracy of the regression equation. Hence it may correctly be reasoned that efficiency depends also on the number of plots that are clipped as compared to the total number of sample observations. If too many plots are clipped, the cost of sampling becomes unnecessarily high, while the use of too few clipped plots results in an unreliable regression equation. Thus, it is desirable to estimate the proportion of clipped plots which may be expected to provide maximum precision with minimum work.

For a regression involving a single independent variable, the optimum proportion of the total number of plots to the number clipped may be calculated if the following factors can be estimated with reasonable precision, *viz.*, the variance of estimate of the regression equation ($V_{y \cdot x}$); the regression coefficient (b); the variance of X (V_{X_L}); the approximate costs of obtaining the values of X and Y at each sampling point (c_x and c_y); and the cost of travel between sampling points (c_t), including setting up equipment at any new point. Then the optimum ratio of the total number of observations (n_L) to the number of clipped plots (n_s) may be estimated approximately from the equation

$$\frac{n_L}{n_s} = \sqrt{\left(\frac{c_y}{c_x + c_t}\right)\left(\frac{b^2 V_{X_L}}{V_{y \cdot x}}\right)}.$$

For this approximate calculation the travel cost per plot may be taken as essentially constant with varying numbers of sample observations, within the limits imposed by a fixed total cost of sampling.

DESCRIPTION OF EXPERIMENTS

In order to fit the studies of sampling methods into active range experiments with maximum efficiency, we tried out the two methods at two different locations. The line-transect trial was made in experimental pastures at the Manitou Experimental Forest, in the headwaters of the South Platte River, while the efficiency of weight estimates was tested in a study of the influence of gopher removal on forage production, located on the Grand Mesa National Forest in western Colorado. Thus, line transects and weight estimates could not be compared directly with each other, but the efficiency of each method could be compared with that obtained by clipping quadrats.

LINE-TRANSECT STUDY

Experimental area.—At the Manitou Experimental Forest six pastures, each 250 to 300 acres in size, have been established to study the influence of three intensities of grazing by cattle on forage production, beef yields, erosion, and infiltration.

The forage on these pastures is primarily a bunchgrass type existing as an understory in an open ponderosa pine stand. Park-like areas from a few square rods to several acres in extent are dominated by bunchgrasses. In areas occupied by open stands of ponderosa pine the same species persist but in lighter density than in the park-like areas. In spots where the canopy is dense, and directly beneath the pines, a few sedge plants are the only species present.

Field procedure.—In ascertaining forage production, a total of 36 plots was sampled in each pasture. At each plot were measured the ground-level diameter (to the nearest 0.01 foot) and the average height (to the nearest 0.10 foot) of the portion of every plant which touched a 30-foot cable stretched between two iron stakes. These plants were classified as to whether grazed or ungrazed, and segregated into four classes, *viz.*, tall bunchgrasses, short bunchgrasses, single-stemmed and sod-forming grasses and grasslike plants, and weeds (forbs). Browse species were ignored, as they form a minute part of the palatable forage in this cover type.

Six of the 36 transects were selected at random for clipping. After the line-transect data were obtained, the vegetation was clipped from a 6-inch by 30-foot belt transect surrounding the 30-foot line-transect. The forage was sorted by classes, air-dried, and then weighed to the nearest gram. In addition to these data, each crew kept accurate notes on the amount of time consumed in clipping, tallying, travel between plots, and handling the clipped forage.

WEIGHT-ESTIMATE STUDY

Experimental area.—The Grand Mesa experiment is factorial in design. Its objective is to discover the influence of grazing by cattle and gophers, separately and together, on forage production and related factors. Sixteen 1-acre areas have been established, four in each of four locations or blocks. The four treatments, cattle and gophers, cattle alone, gophers alone, and no grazing, have been assigned at random to the 4 acres in each block.

The study area is on comparatively level to rolling land at an elevation of approximately 10,500 feet, where the vegetation consists of open grassland and sagebrush interspersed with stands of Engelmann spruce. All observations were confined to the park-like areas of sagebrush and grass-weed communities, since the ground beneath the spruce trees is practically devoid of forage. Grasses constitute approximately 20% of the vegetal cover, varying from 8 to 30%, depending

largely on the intensity of use in the past by grazing animals. Weeds are abundant, constituting from 55 to more than 90% of the cover. On approximately one half of the study area sagebrush is the dominant plant, the understory consisting of grasses and weeds.

Field procedure.—For sampling the forage, each 1-acre area was subdivided into nine strata and two sample plots were assigned at random to each stratum. These plots, each 12.5 square feet in area, provided the large sample. For the small sample, five plots were drawn from the 18 plots in each acre.

Estimates of green forage weight were obtained by one man, who had previously trained himself by estimating the forage on a number of plots and checking his estimates by clipping and weighing the forage. In sampling the experimental plots, each species was estimated separately; then the species estimates were combined into three classes, grasses, weeds, and shrubs.

After the plots had been estimated on a single acre, another worker clipped the forage on the five plots forming the small sample, segregating it into the three classes and weighing the clip in green condition. The estimator was then permitted to compare his estimates with the actual green weights as a running control on subsequent estimates. Finally, the clipped forage was air-dried and reweighed to the nearest gram.

RESULTS

LINE-TRANSECT METHOD

In Table 1 are presented, together with their standard errors, numerical estimates of the air-dry weight (in pounds per acre) of each class of forage on the six pastures as calculated by the double-sampling method. For simplicity and because they were similar in magnitude, the separate pasture standard errors were pooled to provide a single value for each forage class.

TABLE 1.—*Average estimated forage weight in pounds per acre per pasture, by forage classes.*

Pasture No.	Forage class				Total forage
	I	II	III	IV	
1	37.6	154.6	19.9	41.3	253.4
2	26.0	174.0	13.9	48.3	262.2
3	44.9	167.6	16.4	57.0	285.9
4	36.6	112.2	14.7	40.6	204.1
5	42.9	175.5	18.1	46.6	283.1
6	50.3	162.9	23.5	37.1	273.8
Sum	238.3	946.8	106.5	270.9	1,562.5
Mean	39.7	157.8	17.7	45.2	260.4
Standard error	±13.4	±24.0	±4.6	±8.2	±29.0

From these standard errors it is evident that the information on the separate classes is not very precise, although the mean values per pasture for total forage are considerably more accurate. These, in fact, with a standard error of about 11%, may be considered for our purposes to provide satisfactory information on the amount of forage remaining on these pastures at the end of the grazing season.

Several pertinent facts resulted from the double-sampling analysis. For example, the independent variable (summed diameter times height) was well correlated with air-dry forage weight; only the short bunchgrass and weed classes showed relatively poor correlation. In the tall bunchgrass class, 78% of the variation in forage weight was associated with the independent variable; corresponding figures for short bunchgrass, single-stemmed grass, weeds, and total forage were 52, 77, 42, and 68%, respectively.

Also, in this study we found that the individual pasture regressions were homogeneous, and that a single regression could be used with equal accuracy for all six pastures. This fact contributed to the efficiency of the double-sampling method, since the estimated forage weights per pasture could be computed from a single regression based on the 36 small-sample observations obtained in all six pastures rather than from six relatively weak regressions based on only six observations apiece. As a corollary of this fact, it turned out that we employed almost the optimum number of clipped plots as compared to the total number in each pasture. As calculated by the equation on page 196, the optimum ratio of the total number of observations to the number of clipped plots was about 1.13 to 1.00; and since the regression was based on 36 observations, the 36 large-sample observations per pasture gave an actual ratio of 1.00.

As another feature of the line-transect method, relative figures on plant cover density and forage utilization could be derived from the large-sample data. In order to get similar figures from a sample containing only clipped plots, we should have had to make separate density estimates and segregate the clipped forage into grazed and ungrazed plants. This process would have required at least 5 to 10 minutes additional time per plot.

Now, in examining the actual relative efficiency of double-sampling as compared to clipping all plots, we can make comparisons based either on field time requirements or on total time, depending on whether or not field time limits the size of the sample. Considering field time alone,[4] 26 belt transects could have been clipped in the time required for tallying 36 line transects and clipping six belts. Comparing the resulting variances of mean values, the double-sampling procedure provided an increase in information of about 28%. If, on the other hand, the comparison is based on total time expended, the double-sampling method provided only about 11% more information than clipping all plots. Actually, the office time required for the rather complex double-sampling analysis largely offset the savings in field time.

If we wish to apply these results to studies in other places, the several components of field time become important in appraising the relative economy of double-sampling. In our field samples the actual tallying of line transects, including setting up and removing the cable, required 12.4 man-minutes per transect; clipping took up 32.4 man-minutes; and travel between plots, 22.2 man-minutes. If, in another

[4]Including training men, clipping, tallying, setting up and removing equipment, weighing forage, and travel between plots.

study, the plots were much closer together, the double-sampling procedure would be relatively more efficient because travel time would be reduced. In the survey of large areas, on the other hand, with plots relatively far apart or hard to locate, the advantage of double-sampling with line transects might disappear entirely; travel time would be so large that the additional cost of clipping all the plots would form a very small part of the total field time.

WEIGHT-ESTIMATE METHOD

As shown in Table 2, the forage on these 16 1-acre areas was estimated with satisfactory precision. Of the three forage classes, only browse showed poor results; and the sampling errors for total forage are considerably smaller (in percentages of forage weights) than those observed in the line-transect method. By itself this observation does not favor weight estimates, however, as the sampling was considerably more concentrated than in the Manitou experiment.

TABLE 2.—*Average estimated forage weight per acre, by forage classes.*

Acre designation	Forage classes			Total, lbs.
	Grasses, lbs.	Weeds, lbs.	Browse, lbs.	
1-A	159±21*	372±46	370±50	901±86
1-B	192±21	564±40	334±35	1,090±62
1-C	89±13	514±54	154±39	756±66
1-D	135±23	849±47	275±73	1,259±81
2-A	49± 8	540±36	16±16	604±41
2-B	111± 9	723±41	76±22	911±40
2-C	56± 6	652±45	21±14	729±50
2-D	149±18	919±33	54±18	1,122±40
3-A	95±20	244±32	33±21	373±46
3-B	138±16	461±43	41±16	640±59
3-C	95±11	900±92	41±22	1,036±103
3-D	236±22	973±80	79±27	1,288±98
4-A	137±15	427±53	80±20	644±61
4-B	118±17	549±29	38±12	705±43
4-C	158±11	619±39	57±17	834±49
4-D	196±21	990±104	68±24	1,253±123

*The right-hand figure in each cell is the standard error of the average forage weight, in pounds per acre.

Perhaps a better criterion for judgment is provided by the relative precision of regressions of air-dry forage weight on estimated green weight. In general, these correlations were somewhat better than the line-transect results; 78% of the variation in the weight of total forage was associated with weight estimates, and corresponding data for grasses, weeds, and browse were 79, 77, and 72%, respectively.

As to relative time requirements, only 6.7 man-minutes per plot were required for estimating green weights, as compared to 12.4 man-minutes for tallying a line-transect; this considerably lower figure in spite of the much heavier stands of forage on the Grand Mesa. Travel

time was negligible on these small areas and was therefore included in the other two components, while the actual clipping required 68.4 man-minutes per 12.5 square-foot plot as compared to 32.4 man-minutes per 15 square-foot plot in the Manitou pastures.

As observed in the line-transect study, no significant differences existed among the individual acre regressions. Therefore, it was possible to use a single regression (based on the pooled "within acre" squares and products) for estimating the mean forage production on each of the 16 acres. Since, without previous experience, this fact could not have been predicted beforehand, we used a rather inefficient proportion of the total number of plots per acre to the number clipped in each acre. As calculated by the equation on page 196, this ratio should have been about 5.7 estimated plots for each clipped plot. Although 18 plots were estimated and 5 of these plots were clipped on each acre, we actually used a ratio of 0.22 to 1.00 (that is, 18 estimated plots to 80 clipped plots in the regression) in estimating the mean forage production per acre. The efficiency of double-sampling would have been materially improved if only one or two plots had been clipped on each acre and the time thus saved had been used in estimating a larger number of plots per acre.

Even with this relatively inefficient arrangement, double-sampling with weight estimates provided a substantial increase in information as compared to clipping all plots. Only about 6.8 plots could be clipped in the field time required for double-sampling with 5 clipped and 18 estimated plots per acre. As a result, the latter method provided about 37% more information on total forage than that supplied by clipped plots. When the comparison is based on total time (field and office), the gain in information dropped to about 14%. These gains are not greatly different from the line-transect results. If, however, only one plot had been clipped on each acre and the surplus time used in estimating about 40 additional plots per acre, the variance of the calculated mean forage weight would have been reduced by about one third, and the relative efficiency of double-sampling would have been correspondingly increased.

DISCUSSION

As a result of these analyses, we have a definite basis for quantitative comparison of each double-sampling method with the cost of clipping sample plots in our experiments, and a qualitative basis for comparing the two methods with each other.

As employed in these studies, both short-cut methods provided a substantial saving in field time and some economy on the basis of total time expended. The achievement of similar economies in other studies would probably depend, however, on the relative amounts of time required for clipping, traveling to and from the survey area and between sample plots, and applying the short-cut method. In experiments requiring intensive sampling by trained men, with sample plots located close together, either of the double-sampling methods may be expected to provide substantial increases in efficiency as compared to clipping all sample plots. In large-scale, extensive range

surveys, on the other hand, travel may often be the largest component of total cost; especially in surveys of remote mountain areas, involving transportation by horse and repeated camps in relatively inaccessible areas. Under such conditions it may frequently be found that the cost of clipping all sample plots forms a small part of total costs, and yields rich returns in the precision of survey information as compared to the usual qualitative estimates of forage density and similar factors. Under critical scrutiny the sampling of such relative factors, without the quantitative check provided by double-sampling, tells the investigator only that one sample average is larger or smaller than another. It fails to give him quantitative information on the actual amounts of forage present on each sampled area and on the error of each sample average in terms of forage weight.

In comparing the two double-sampling methods with each other, our only definite statement can be that they showed no substantial difference in efficiency as used in our studies. Weight estimates may, however, be judged superior to line transects, simply because they required less time in the field and seemed to give at least equally precise estimates of forage weight. Also, as we used it, the weight-estimate method suffered from the use of an inefficient proportion of the total number of observations per acre to the number used in the small-sample regression. With a more efficient design, this method might have turned out to be decidedly superior to the line-transect method.

In general, our feeling is that these studies have not solved the problem of sampling range forage efficiently, although they have provided a step toward its solution. The principal difficulties still remain, *viz.*, forage is highly variable, with the result that adequate sampling must still require a considerable expenditure of time.

SUMMARY

Two double-sampling methods, using line-transects and forage weight estimates, were tested to ascertain their relative efficiency in estimating the amount of forage present on experimental areas, as compared to the clipping of vegetation on sample plots.

Considering field work alone, double-sampling with the line-transect method provided an increase in information of about 28% as compared with the information which could have been obtained by clipping only, during the same period of time. On the basis of time expended in both field and office, the double-sampling method provided only about 11% more information than could have been obtained by clipping alone.

The use of weight estimates in double-sampling provided about 37% more information than could be obtained by straight clipping in an equivalent amount of field time. If field work and office compilation are both considered the gain in information dropped to about 14%.

Under our conditions of intensive sampling both methods provided substantial economies in field time and some saving in total time expended. In other studies, however, these savings would be consider-

ably affected by the relative amount of time consumed in field travel as compared to the time requirements of clipping and double-sampling. In large-scale extensive surveys, the clipping of all plots may prove to be at least as efficient as any short-cut method.

LITERATURE CITED

1. BERULDSEN, E. T., and MORGAN, A. Sampling technique as applied to irrigated pasture in regard to botanical composition and carrying capacity under different grazing systems. Jour. Dept. Agr. Victoria, 29:36–45. 1934.
2. CANFIELD, R. H. Application of the line interception method in sampling range vegetation. Jour. Forestry, 39:388–394. 1941.
3. ————. Sampling ranges by the line interception method. Research Report No. 4. Southwestern Forest and Range Exp. Sta., U. S. Forest Service. 1942. (Mimeographed.)
4. DAVIES, J. G. Experimental error of the yield from small plots of natural pasture. Australian Council for Sci. and Ind. Res. Bul. 48. 1931.
5. ELLENBERGER, H. B., NEWLANDER, J. A., and JONES, C. H. Yield and composition of pasture grass. Vt. Agr. Exp. Sta. Bul. 295. 1929.
6. PECHANEC, J. F., and PICKFORD, G. D. A weight estimate method for the determination of range or pasture production. Jour. Amer. Soc. Agron., 29:894–904. 1937.
7. ROBINSON, R. R., PIERRE, W. H., and ACKERMAN, R. H. A comparison of grazing and clipping for determining the response of permanent pastures to fertilization. Jour. Amer. Soc. Agron., 29:349–359. 1937.
8. SCHUMACHER, F. X., and CHAPMAN, R. A. Sampling methods in forestry and range management. Duke Univ. School of Forestry Bul. 7. 1942.

THE INFLUENCE OF SEASONAL CONDITIONS ON OIL FORMATION AND CHANGES IN THE IODINE NUMBER DURING GROWTH OF FLAXSEED[1]

EDGAR PAGE PAINTER, L. L. NESBITT, AND T. E. STOA[2]

FACTORS which are known to influence the iodine number of linseed oil and the oil content of the seed are (a) variety and (b) weather conditions. Although some evidence that soil elements may influence the iodine number may be adduced from studies on mineral metabolism of flax, addition of fertilizers have, for the most part, given inconclusive results. The range found by a comparison of Bison, Rio, Redwing, and Linota (3)[3] was about 4% in oil content and about 10 points in iodine number. A much wider range has been found between the iodine number of high and low iodine number oil producers when all varieties compared at the North Dakota Experiment Station are included.

SEASONAL VARIATIONS IN IODINE NUMBER AND OIL CONTENT

By far the most important known factors are weather conditions during the period of growth of the flaxseed. Differences of 10% in oil content and 40 points in the iodine number in the same variety grown under different weather conditions are not uncommon. A range of 60 points in the iodine number of oils from a single variety (3) has been found. When the factors of weather and variety are additive, the range may be greater. The composition of linseed oils (10) with a range in iodine number from 127.8 to 202.8 has recently been reported by the authors.

Hopper and Johnson (5) and Dillman and Hopper (3) have made comprehensive studies of the effects of temperature and rainfall on flaxseed production. They considered July the critical month for flax. Both the iodine number and oil content were markedly reduced by high temperatures. Correlation coefficients between July temperature and iodine number were slightly larger than between temperature and percentage of oil. Both were negative and highly significant. The relationships between precipitation and iodine number or total oil were not particularly significant. From studies on commercial samples of flaxseed from known shipping points in North Dakota and Minnesota (5), the oil content was positively correlated with July precipitation but not with crop year precipitation. The iodine number did not appear to be determined by precipitation to any appreciable extent. On the other hand, the results of a more extensive study (3), covering 1 to 10 crop years at 54 different stations, many of which are outside of the major flax-producing region and where

[1]Contribution from the Department of Agricultural Chemistry and Agronomy, North Dakota Agricultural Experiment Station, Fargo, N. D. Published by permission of the Director. This work was carried out under Purnell project 95, "The Chemistry of Flaxseed". Received for publication August 19, 1943.

[2]Chairman, Department of Chemistry; Assistant Agricultural Chemist; and Chairman, Department of Agronomy, respectively.

[3]Figures in parenthesis refer to "Literature Cited", p. 213.

moisture is rarely a limiting factor and widely dispersed over North America, showed both the iodine number and percentage of oil to be related to crop year precipitation but not to July precipitation.

COMPARISON OF 1941 WITH 1942 CROP

Much of the data for the studies just cited were obtained in a series of hot, dry seasons which occurred in the major flax-producing region of this country. The 1941 and 1942 growing seasons differed in such a way as to offer an unusual opportunity to investigate the effect of temperature and rainfall on the oil content and iodine number of the oil. July temperatures and precipitation at three locations where several varieties of flax were grown each season are shown in Table 1.

TABLE 1.—*Temperature and rainfall records for 1941 and 1942.**

Location	Average July temperature, °F		Mean maximum July temperature, °F		Maximum July temperature, °F		July rainfall, inches		Accumulated rainfall to July 1, inches	
	1941	1942	1941	1942	1941	1942	1941	1942	1941	1942
Fargo...	72.8°	68.8°	85.1°	81.1°	104°	94°	0.84	0.87	11.70	10.92
Langdon.	69.2°	64.1°	83.8°	78.0°	100°	94°	1.48	4.44	13.83	8.66
Edgeley .	71.2°	67.7°	85.7°	80.2°	102°	94°	0.86	1.86	12.94	13.61

*Taken from reports of U. S. Weather Bureau climatological data.

The oil content and iodine number of a group of samples grown at the locations indicated in Table 1 during 1941 and 1942 are shown in Table 2.

Differences in the percentage oil content of the flaxseed grown during each of the two seasons are small and not consistent. At Fargo the average in 1941 was 1.6 points higher than in 1942, while at Langdon and Edgeley the average in 1941 was less than that of 1942 by 1.5 and 3.0 points, respectively. The oil content of the 1941 Edgeley samples was lower than generally found in the state.

Unlike the differences in oil content, much higher iodine numbers were found in 1942 than in 1941. The 1942 average minus the 1941 average (Table 2) of the groups grown at Fargo (20.6), at Edgeley (24.6), and at Langdon (18.8) are surprisingly large. At each station the mean as well as maximum July temperatures (Table 1) were considerably higher in 1941 than in 1942. Lower temperatures while the seed ripened appears to be the logical explanation for the higher iodine numbers in 1942.

Precipitation may be a contributing factor, but the data indicate that the iodine number of linseed oil is influenced much more by temperature than by rainfall. Total precipitation (Table 1) for specified periods may be misleading, because the benefit of rainfall to crops is determined largely by timely distribution. June rainfall in 1941 exceeded June rainfall in 1942 at all stations. Moisture at Fargo and Edgeley was in excess of normal in June 1941, so that, despite a low July rainfall each season, soil moisture conditions in early July

1941, when flax plants become heavy users of water, were presumably better than in 1942. At Langdon, June rainfall, as well as total precipitation up to July 1, 1942, was far below that in 1941. The deficiency, however, was largely made up by a heavy July rainfall. Although the seasonal distribution of rainfall indicates that during the development of the flaxseed at Fargo moisture was more abundant in 1941 than in 1942, loss of water by evaporation was greater in 1941.

TABLE 2.—*Total oil and iodine number of the oil from flaxseed grown in 1941 and 1942.*

Variety	Iodine number		Oil content, %*	
	1941	1942	1941	1942
Fargo				
B. Golden	171	193	43.9	43.2
Biwing	175	187	44.2	40.6
Buda	166	187	44.1	40.4
Bison	158	181	43.5	42.2
Viking	173	193	43.2	42.7
Koto	164	185	44.6	41.3
B. 5577	157	183	43.5	43.0
C.I. 970	179	189	43.0	40.6
B. 5593	159	189	42.9	44.2
B. 5585	167	188	42.7	41.5
Av.	166.9	187.5	43.6	42.0
Langdon				
Bison	166	188	40.9	40.4
Buda	171	188	38.8	40.8
B. Golden	179	196	40.6	44.8
Walsh	165	184	41.7	42.2
Av.	170.2	189.0	40.5	42.0
Edgeley				
Bison	157	184	39.0	42.0
Buda	166	186	36.5	39.9
B. Golden	164	193	36.5	42.5
Walsh	152	181	39.1	41.1
C.I. 970	172	190	39.2	40.1
Av.	162.2	186.8	38.1	41.1

*Percentage oil calculated to moisture-free basis.

CHANGES IN IODINE NUMBER AND RATE OF OIL FORMATION DURING GROWTH

Oil begins to form in flaxseed soon after blossoming (6). Oil formation is very rapid between the tenth and twentieth day after flowering (1, 4), but oil may continue to be laid down as long as there is an increase in seed weight (9). Under cool, moist conditions, more than 50 days may elapse between blossoming and full maturity, but under hot, dry conditions, such as sometimes occur in the major flax-producing

region of this country, the ripening period may be less than 30 days. Accompanying the increase in oil content there is usually an increase in the iodine number. Under ideal growing conditions a rapid increase of the iodine number may follow 4 or 5 days behind oil accumulation (1, 4), but when weather conditions are unfavorable (7, 9) the increase may be arrested before all of the oil is deposited in the seed.

The total oil formed and the iodine number of the oil in the seed when harvested then depends upon two separate reactions, *viz.*, (a) the rate and period (days) of oil formation, and (b) the rate and period of increase in iodine number. The rates are not constant throughout the period of growth. Reaction (b) may be modified by the iodine number of the oil first laid down. The results in Table 2 give the oil content and the iodine number of the oil from mature seed. They do not give a clue as to what enzymatic reactions were inhibited or accelerated to produce oils of different unsaturation in each of the two years.

Although considerable data have been reported on the deposition of oil in flaxseed (1, 2, 4, 7, 8, 9, 11), only in the work of Eyre (4) and of Barker (1) was the experimental procedure carried out in such a way as to follow true rates of oil formation and of changes in the iodine number. Climatological data have not been adequate to show the influence of the season on the course of the reactions which regulate the quantity and character of the crop produced.

The rate of oil formation and changes in the iodine number during the oil formation period in the 1941 and 1942 seasons have been followed in flax grown at Fargo. For this purpose a large number of flax blossoms were tagged the day of blossoming, and boll samples were collected at intervals of 2 to 5 days until ripe. Bison was the variety chosen for study of oil deposition in 1941 and B. Golden in 1942. Both varieties are high in oil but B. Golden produces an oil which, on the average, has an iodine number about 10 points higher than Bison. The green flax bolls from tagged blossoms harvested in the present work were dried rapidly at 65°C in an oven equipped with a circulating fan so that oil formation and increase in iodine number, which normally takes place when immature flax bolls are allowed to air-dry (1, 4), were inhibited.

In Fig. 1 the growth period of each sample of flaxseed, daily mean and maximum temperature, and rainfall from July 2 until August 18, 1941 and 1942, are shown. The growing period of each sample is shown by horizontal bars. Temperature and rainfall during the days of growth of each sample may be determined by drawing vertical lines from the horizontal bars.

The prolonged period of excessively high temperatures in 1941 is clearly shown in Fig. 1. A question may be raised as to whether or not July climatological data are adequate for studies of the effect of weather on the iodine number of linseed oil. High temperatures in 1941 extended until August 6 and the flax was not fully mature until after this date.

Table 3 shows the analytical results on the samples collected each year. The proportion of total oil formed (column 5) was calculated from weights of oil in column 4. The highest weight of oil per 1,000

seeds was considered 100%, or the total oil. The other values in column 5 show the percentage of this total oil represented by the weights of oil per 1,000 seeds at each collection date.

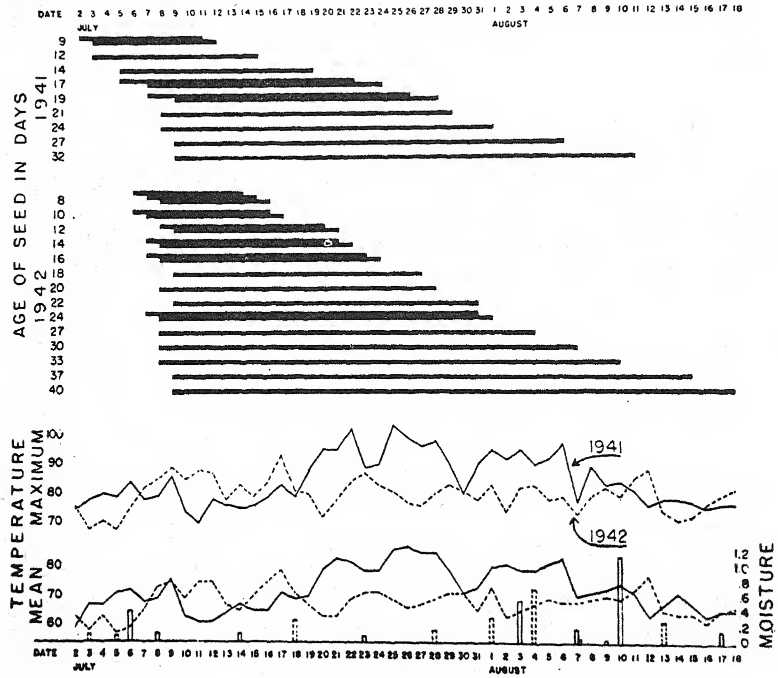


FIG. 1.—Growing period of flax samples. Left end of solid lines indicate date of tagging; right end, date sample was taken; length of line, period of growth. Double and triple lines designate samples taken from flowers tagged two and three dates. Daily mean and maximum temperatures and precipitation (in inches) for the periods the flax grew are also shown. 1941 precipitation is indicated by columns with continuous lines.

Oil deposition is shown in Fig. 2 and changes in the iodine number in Fig. 3.

The results (Figs. 2 and 3) show a more rapid rate of oil formation and increase in iodine number than those of other studies of flaxseed grown in the major flax-producing region of this country and Canada, as reviewed by Nesbitt, *et al.* (9). Very little oil is deposited in the first few days after blossoming. Although oil deposition (Fig. 2) was more rapid than found by Eyre (4) and Barker (1) in flaxseed grown in northern Ireland, the period of oil formation was about 20 days shorter. Oil formed at approximately the same rate each year, but in 1942 oil continued to accumulate for about 5 days longer than in 1941.

The highest percentage of oil was found at 24 days in 1941 and at 27 days in 1942. Oil continues to be formed after the maximum percentage of oil in the seed has been reached. Seed weight continues to

TABLE 3.—*Analytical results on flaxseed harvested at regular intervals after tagging blossoms.**

Days grown, tagging to collection	Weight per 1,000 seeds, grams†	Oil content of seed, %†	Oil per 1,000 seeds, grams	Proportion of total oil accumulated, %	Iodine number of oil
		1941			
9	1.73	10.5	0.182	8	150
12	2.52	24.6	0.620	28	164
14	2.82	26.4	0.745	33	162
17	3.72	37.9	1.408	63	157
19	4.38	39.2	1.716	76	155
21	5.17	40.5	2.093	93	156
24	5.55	40.6	2.253	100	155
27	5.40	40.3	2.173	97	157
32	5.59	40.1	2.244	100	156
		1942			
8	1.56	9.3	0.145	5	135
10	2.20	16.3	0.359	11	141
12	2.57	25.0	0.643	20	158
14	3.05	33.2	1.013	32	174
16	3.72	38.6	1.436	45	182
18	4.34	42.5	1.845	57	188
20	4.85	44.5	2.158	67	193
22	5.40	45.9	2.479	77	193
24	5.77	45.8	2.643	82	195
27	6.52	46.7	3.045	95	198
30	6.96	46.2	3.216	100	197
33	7.00	44.6	3.122	97	195
37	7.10	44.5	3.160	98	195
40	7.26	44.0	3.194	99	193

*Bison (C.I. No. 389) grown in 1941, and B. Golden (C.I. No. 644) grown in 1942.
†Calculated to moisture-free basis.

increase so that oil may continue to accumulate even though the percentage of oil decreases. Maximum oil (weight of oil per 1,000 seeds) was found at 24 days (at the same time as maximum percentage) in 1941 and at 30 days in 1942, but a careful inspection of the data (Table 3 and Fig. 2) indicates that the results on these two samples are out of line. The total weight of oil dropped at the next collection of seed each year, then increased to near the maximum. It seems likely that oil was being formed throughout the period covered, but at a very slow rate near the end of the seed collection period. The apparent discrepancies are most likely due to inaccurate determination of the seed weight. It must also be recognized that plots are not perfectly uniform, and the blossoms were not all tagged the same day so not all samples developed under identical conditions. All the 1942 samples were tagged within 3½ days and growing conditions were quite uniform, but in 1941 the samples were tagged over 8 days and wide variations in temperature occurred during the oil-forming period. For this reason the 1942 data are considered more reliable than the 1941 data.

The rates of change in the iodine number (Fig. 3) show an unexpected picture. In 1941 the iodine number increased from 150 on

the 9th day after flowering to 164 on the 12th day. Then, instead of continuing to increase, it dropped several points and later leveled off before all the oil was deposited in the seed. In 1942, the iodine number increased regularly from 135 on the 8th day to a maximum of 198. After reaching a maximum it dropped slightly. The increase in 1942 was much more rapid than heretofore reported in flaxseed

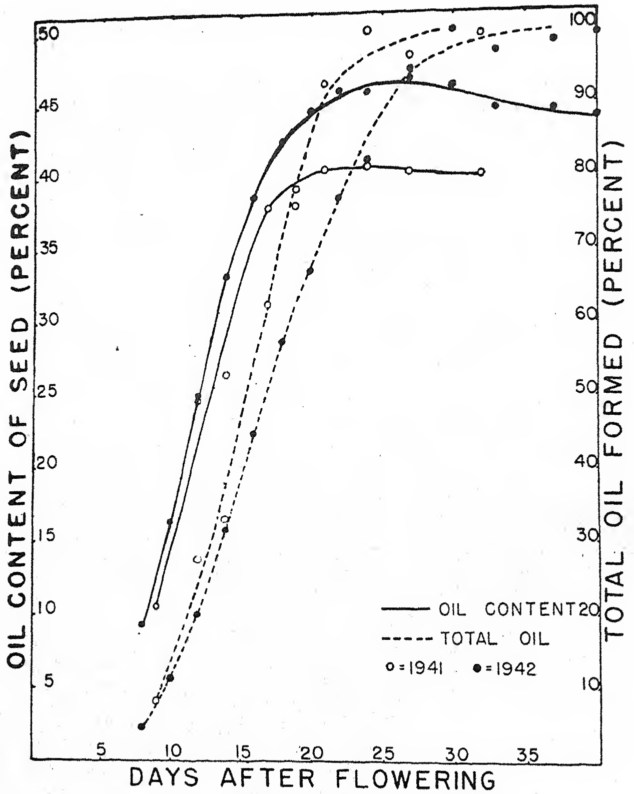


FIG. 2.—Rate of oil deposition as shown by percentage of oil in the seed and proportion of total oil formed.

(9). The highest iodine number was found at 12 days after flowering in 1941 and at 27 days in 1942 (Table 3). In Ireland (1, 4) and in Canada (8), the highest iodine number was sometimes not reached until 50 days after flowering. In 1941, the increase in iodine number was followed through a short period, but apparently the initial rate of increase was more rapid than in 1942 because the iodine number was 150 at 9 days in 1941 and 141 at 10 days in 1942.

From the results of the last two seasons and those summarized (9), it appears possible to predict the course of oil deposition in flaxseed when grown under different conditions. When flax is grown under adverse conditions, presumably due to a combination of drouth and

high temperatures, both the oil content of the seed and iodine number of the oil are very low. Under these conditions, which in 1936 produced flaxseed at Fargo with an oil content of less than 30% and iodine numbers of less than 150, both the oil content and iodine number increase rapidly in the initial stages of development (9), but the changes are arrested at an early stage of growth. Oil may, however,

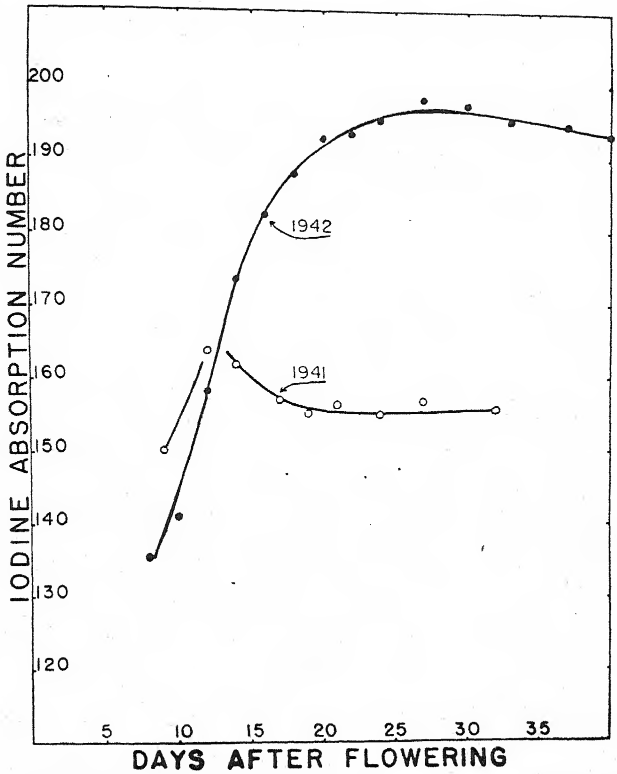


FIG. 3.—Changes in the iodine absorption number of oil from flaxseed collected at known periods of growth.

reach near optimum levels under growing conditions which inhibit the formation of high iodine number oils. In the 1941 growing season oil reached near optimum levels, but the increase in iodine number was inhibited at an early stage of growth. In the unusually favorable growing season at Fargo in 1942, the oil content was high and the iodine number continued to increase until it reached a high value. Although the iodine number did not continue to increase for as long a period as when flax is grown under the conditions in Ireland or Canada, the rate of increase was more rapid so that the iodine number of the oil from the mature seed was as high as usually found at the latter locations.

The iodine number did not continue to increase after all of the oil was deposited in seed as reported (4, 11). It is doubtful if the oil first laid down in the seed is saturated because the iodine number was 135 when only 4.5% of the total oil had been formed.

High temperature, which prevailed during the latter part of July and the first week of August in 1941 (Fig. 1), may account for the low iodine number of the oils from the 1941 crop, but it does not explain the sudden decrease in the iodine number of the oils which were from seeds harvested 12 and 14 days after blossoming (Figs. 1 and 3). Maximum temperatures above 90 did not occur in 1941 until July 20 and the third sample (14 days after blossoming) was collected July 19. During a similar period in 1942 temperatures were actually higher than in 1941, yet the iodine number of the oil increased regularly in 1942. Variations in maximum temperature were less during the 1942 than the 1941 growing period, and after July 18, 1942, generally cool weather prevailed until the flax crop was ripe.

The significant decrease in the iodine number, which occurred in 1941 before the onset of excessively high temperatures, raises a question as to what are the factors which determine the iodine number of linseed oils. Obviously, temperature and rainfall do not tell the whole story. There were somewhat more hours of sunshine in 1942 than in 1941 and the relative humidity in 1942 was slightly higher than in 1941. Average daily variations in temperature were almost identical the two years. Temperature and rainfall are the most important factors now known, but it seems probable that unrecognized environmental conditions contribute to the character of the oil of flaxseed.

SUMMARY

A group of flax varieties were grown at Fargo, Langdon and Edgeley, N. D., during the 1941 and 1942 seasons. Small differences in the oil content were found, but the iodine number of the 1942 oil samples averaged over 20 points higher than that of the 1941 samples. July maximum, as well as average temperatures, were much higher at each location in 1941 than in 1942. Rainfall distribution differed at the three stations each season, but at Fargo moisture was more abundant during the early period of development of the seed in 1941 than in 1942.

Flax blossoms were tagged at Fargo each season and samples harvested at regular intervals to follow the rate of oil deposition in the seed and changes in the iodine number. Oil deposition was rapid each year. The iodine number increased rapidly in 1942 during the period of rapid oil formation, but in 1941 the iodine number increased until about 12 days after blossoming, then decreased. The decrease was during the period of rapid oil formation and it came before the onset of high temperatures.

Whereas excessively high July temperatures appear to account for the low iodine number of the 1941 crop, there seems to be no apparent explanation for the sudden drop in the iodine number during the oil-formation period. It is concluded that unrecognized environmental factors influence the iodine number of linseed oils.

Whether or not high iodine number linseed oils are produced appears to depend upon the duration of the period of increase. The initial rate of increase of the iodine number is rapid when flax is grown under unfavorable growing conditions, but the increase is inhibited at an early stage of growth. Oil, on the other hand, continues to be deposited in the seed under conditions which will inhibit the increase in iodine number. When the season is very unfavorable, presumably due to a combination of drought and high temperatures, oil formation may also be inhibited.

LITERATURE CITED

1. BARKER, M. F. Development of oil in the seed of the flax fiber crop and the variations in its character with maturity. Jour. Soc. Chem. Ind., 51:218–222T. 1932.
2. DILLMAN, A. C. Daily growth and oil content of flaxseed. Jour. Agr. Res., 37:357–377. 1928.
3. ———— and HOPPER, T. H. Effect of climate on the yield and oil content of flaxseed and on the iodine number of linseed oil. U.S.D.A. Tech. Bul. 844. 1943.
4. EYRE, J. V. Notes on oil development in the seed of a growing plant. Biochem. Jour., 25:1902–1908. 1932.
5. HOPPER, T. H., and JOHNSON, M. Flax production and climate of North Dakota and Minnesota, 1919–1937. N. D. Agr. Exp. Sta. Bul. 298. 1941.
6. IVANOV, S. Metabolism of oily seeds upon ripening, etc. Beihefte Botan. Centr., 28:159–191. 1912.
7. JOHNSON, I. J. The relation of agronomic practice to the quantity and quality of the oil in flaxseed. Jour. Agr. Res., 45:239–255. 1932.
8. LEHBERG, F. H., MCGREGOR, W. G., and GEDDES, W. F. Flax studies. IV. The physical and chemical characteristics of flaxseed at progressive stages of maturity. Can. Jour. Res., 17,C: 181–194. 1939.
9. NESBITT, L. L., PINCKNEY, A. J., STOA, T. E., and PAINTER, E. P. Oil formation in flaxseed. Changes in oil constituents of seed from flax plants harvested at regular intervals after full bloom. N. D. Agr. Exp. Sta. Tech. Bul. 323. 1943.
10. PAINTER, E. P., and NESBITT, L. L. Thiocyanogen absorption of linseed oils, linoleic and linolenic acids and composition of linseed oils. Ind. and Eng. Chem., Anal. Ed., 15:123–128. 1943.
11. THEIS, E. R., LONG, J. S., and BEAL, G. F. Drying oils. XIII. Changes in linseed oil, lipase and other constituents of the flaxseed as it matures. Ind. and Eng. Chem., 22:768–771. 1929.

SELF- AND CROSS-FERTILITY RELATIONSHIPS AND CYTOLOGY OF AUTOTETRAPLOID SWEET CLOVER, *MELILOTUS ALBA*[1]

I. J. JOHNSON AND J. E. SASS[2]

THE development of the colchicine technic has given plant breeders and cytologists an opportunity to evaluate the potentialities of chromosome doubling as a method of plant breeding and to study the cytological behavior of these new forms. During the past few years a large number of papers have been published on induced autopolyploids and amphidiploids in plants. Because of the very extensive literature in this field, only those papers that have a direct relationship to the present study will be reviewed.

Although differences between diploid and autotetraploid plants have been studied in several species, the significance of these differences from the standpoint of crop improvement cannot be adequately evaluated at the present time. In general, autotetraploids can be distinguished from the diploids by differences in pollen and stomata size, the former usually showing increases of 25 to 30%. In vegetative vigor the differences are not always consistent and, as suggested by Randolph (7),[3] there may be an upper limit or threshold value beyond which an increase in chromosome numbers may be detrimental to the growth of the plant. In many cases, however, the autotetraploids are larger, more sturdy, darker green, have larger floral parts, and are later in maturity. Differences in chemical composition also have been noted (6, 8, 12).

One of the most striking differences between diploids and experimentally induced autotetraploids is in respect to reduction in fertility. In crop plants propagated by seed, reduced fertility may constitute the most important feature limiting the potentialities of autotetraploid forms. It should be recognized, however, as pointed out by Muntzing (4), that natural autotetraploids are relatively high in seed production in comparison with those artificially produced. Evidently natural selections has effectively modified fertility as in *Dactylis glomerata*, *Agropyron cristatum*, *Hordeum bulbosum*, and *Arrhenatherum elatius*. It is of significance to note that the chromosome number of these autotetraploids is within the modal class of many crop plants.

Studies on autotetraploid maize reported by Randolph (7) show that inbreeding of hybrid tetraploid stocks resulted in the segregation of relatively fertile and highly sterile inbred lines, while tetraploids produced by doubling diploid inbred lines were highly sterile. These results indicates the possibilities of selection for increased fertility in heterozygous stocks. From a study of self-fertile and self-sterile lines

[1]Contribution from the Farm Crops Subsection and the Botany and Plant Pathology Section, Iowa Agricultural Experiment Station, Ames, Iowa. Journal paper J-1147. Project 152. Received for publication September 16, 1943.

[2]Research Professor of Farm Crops and Research Assistant Professor of Botany, respectively.

[3]Figures in parenthesis refer to "Literature Cited," p. 227.

of autotetraploid maize, Fischer (3) concluded that sterility was due mainly to genetic factors and not to cytological irregularities. Evidence was also obtained indicating genetic factors for self- and cross-incompatabilities. Some self-compatible lines were cross-incompatible in crosses with other self-compatible lines when used as the seed parent but cross-compatible when used as the pollen parent. The author (3) postulated that differential cross- and self-fertility in the tetraploids may be explained on the basis that when the chromosome number was doubled a change resulted in genic balance due to the cumulative and proportionate increase in effectiveness of some genes while others remained static in their activity. Doubling of the chromosome number may therefore reveal certain genes which in the diploid state may be inhibited by the action of epistatic factors or modifiers.

The cytological behavior of colchicine-induced autopolyploids is characterized by multivalent chromosome association at meiotic metaphase, erratic anaphase separation, and abortion of microspores. Recent confirmation of these phenomena has been presented by Sparrow, Ruttle, and Nebel (11), Smith (10), Bergner, Avery, and Blakeslee (1), Fischer (3), and O'Mara (5). These meiotic irregularities are associated with sterility, but the degree of sterility in specific cases may not be correlated with the extent of meoitic irregularity (3, 11). Smith (10) has reported a striking histological aberration in the leaves of an octoploid *Nicotiana*, in which the mesophyll does not exhibit distinctive palisade and spongy zones. Critical cell-lineage studies of chemically induced and x-ray induced chromosomal aberrations have been made by Satina and Blakeslee (9) and Brumfield (2).

Because of the importance of seed production in the utilization of autotetraploids, the present study was made to determine the variations in self-fertility and differences in cross-fertility among selected plants and to determine their histological and cytological characteristics. Investigations are in progress on the effectiveness of inbreeding and selection for increased fertility, on the inheritance of self-fertility levels in crosses, and to ascertain in further detail the cytological basis for differences in seed setting.

EXPERIMENTAL METHODS

Autotetraploid plants were produced by submerging the cotyledons and stem tips of 3 to 5-day-old seedling in a 0.05% aqueous solution of colchicine for 6 hours. Seed was germinated on filter paper in petri dishes until the radicle had elongated to 1 inch. The seed coats were removed and the young seedlings oriented on a 2×5 inch filter paper with all cotyledons at the edge. The filter paper was then rolled and placed in an upright position in a beaker partially filled with water and allowed to stand in rather low light intensity at room temperature for 2 to 3 days, until the cotyledons were ½ inch above the filter paper. The roll was then inverted and suspended with clamps attached to a ring stand so that the cotyledons and stem tips were immersed, but the filter paper was not touching the colchicine solution. After 6 hours, the cotyledons were thoroughly rinsed and the seedlings transplanted into sand. Over 90% of the transplants survived. Similar treatment in 0.1% concentration for 3 hours was also effective, but immersion for longer periods gave low survival after transplanting. Preliminary studies had

shown that seed treatment was not successful because colchicine, even at low concentrations (0.5%), apparently injured the primary root to the extent that seedlings could not become established even though the cotyledons appeared to be normal.

Cuttings were made from the rapidly growing tops of plants approximately 3 months old. The cuttings were treated with an aqueous solution (100 p,p.m.) of beta indoleacetic acid for 8 hours, allowed to become well rooted in clean sand, and then transferred to 4-inch pots. After the plants became pot-bound, root tips were removed and killed in the following "Craf" formula, in which root tips can be stored indefinitely.

1% chromic acid	50 cc
10% acetic acid	35 cc
U.S.P. formaldehyde	15 cc

Dehydration was carried out through a 5-grade dioxan series; standard methods were used for infiltration in paraffin, sectioning, and staining. Sections of the meristematic zone were stained in iodine-gentian violet for chromosome counts. The seriated sections behind the promeristem were stained in safranin-fast green for histological comparisons. Temporary aceto-carmine preparations of microsporocytes were used to verify chromosome counts and to ascertain the character of association and disjunction.

All studies on self- and cross-fertility were made during the winter and early spring in the greenhouse. Plants grown from cuttings or from seed were established in 4-inch pots in October and subjected to light from 200-watt clear Mazda bulbs during the night and also during the day in cloudy weather. With this light treatment, in a greenhouse maintained at 70° to 75° F, the plants bloomed 3 months after planting and continued to flower for a period of over 3 months.

Selfing was accomplished by daily tripping of florets with a toothpick as they opened progressively on a raceme. Under greenhouse conditions, each raceme produced from 40 to 60 florets and the self-fertility of a plant was determined from either two or three racemes. To minimize the confounding of fertility with environmental effects, all plants in a specific comparison were studied during the same time interval.

In emasculating for crossing, the petals were removed with forceps and the anthers and free pollen removed by means of air suction through a glass tube drawn to a very fine bore, attached to the rubber tube of an air suction pump. Preliminary studies on tetraploid plants had shown that the percentage of natural selfing from open-flower emasculation with the technics employed was very low (less than 1%) when the florets were left unpollinated. If florets are well pollinated when making a cross, the probability of natural selfing should be further reduced. Emasculation of unopened buds was found to cause some damage and therefore this method could not be used because seed set in crosses would not be comparable to seed set by selfing.

To obtain comparisons of self- and cross-fertility, two racemes at the same stage of development on different branches of the plant were selected, one raceme was arbitrarily chosen for crossing and the other for selfing. Cross- and self-pollination were started on the same day and terminated on the same day to reduce to a minimum any possible variation due to fluctuations in environment.

Pollen diameter measurements were made at 450 magnification with an eyepiece micrometer. Slides were made of pollen from freshly opened florets and tap water was used for making pollen preparations.

Measurements of stomatal length were made from the lower epidermis of fully expanded leaves. The tissue was peeled and mounted in aceto-carmine, which produces uniform expansion of the guard cells regardless of the state of turgor of the specimen when collected.

EXPERIMENTAL RESULTS

COMPARISON OF MORPHOLOGY OF DIPLOIDS AND TETRAPLOIDS

Morphological differences between autotetraploid and diploid plants were very marked. Tetraploids were characterized by a slightly more robust growth, darker green color, broader and thicker leaves, more prominent serrations at the margin of the leaf blades, shorter internodes, thicker stems, larger floral parts, and a more pronounced aroma of the flowers. These differences are in general agreement with those reported for other autotetraploid plants. Among seedlings treated with colchicine, the tetraploids or those with tetraploid sectors could be distinguished readily from the unaffected seedlings by the greatly reduced unifoliate leaf of the former. These differences are shown in Fig. 1, taken 10 days after transplanting from filter papers to sand in flats.

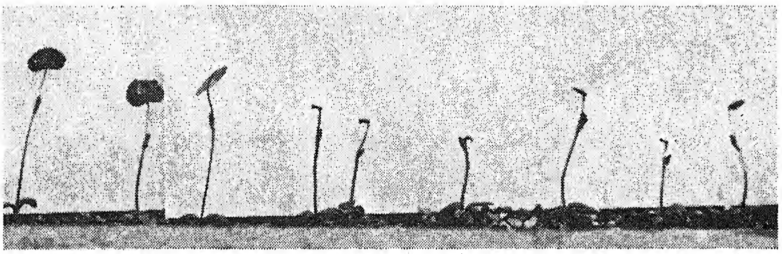


FIG. 1.—Treated seedlings, unaffected diploids at left, possible tetraploids at right.

Leaves of the tetraploid were thicker than those of the diploid. With well developed leaves the difference was detectable by touch. Micrometer caliper measurements were made, but because of the difficulty of applying uniform pressure with the screw, these measurements are only approximations. Tetraploid leaf blades attained a thickness of 0.3 mm, whereas diploid leaves rarely exceeded 0.22 mm. These dimensions include the variable thickness contributed by the veinlets.

Stomatal size is known to be a useful criterion of polyploidy. The present material exhibited the expected differences. Based on measurements from four lines, stomates of the diploid averaged 26.4 microns and stomates of the tetraploid 36.1 microns, representing an increase of 36.7%. Because of the extremely irregular outlines of the epidermal cells, no attempt was made to compare dimensions and volumes of these cells of 2n and 4n plants. However, marked structural differences of diagnostic value were found. The pronounced angularity and thickened corners of 4n epidermal cells, in comparison with the rounded lobes of 2n cells, were almost as reliable an indica-

tion of tetraploidy as stomatal dimensions. The guard cells of 4n plants exhibited prominent protuberances of the cell wall, projecting into the adjacent cells (Fig. 2).

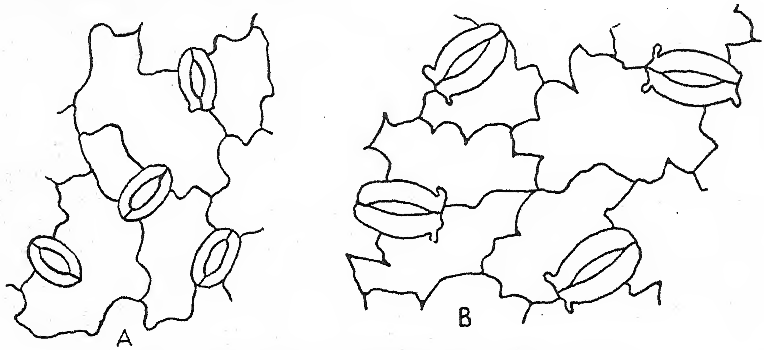


FIG. 2.—Epidermis. A, diploid; B, tetraploid. 500×.

Histological comparisons and measurements were also made, using paraffin sections. The terminal leaflet of the leaf subtending the lowest major inflorescence was used, and transections were made across the midregion. In both tetraploid and diploid leaves, the palisade parenchyma consistently was one layer of cells, occupying approximately the same depth as the spongy zone. The two zones thus contribute equally to the greater thickness of the tetraploid. Measurements of regions between veinlets were made by microprojection. It should be recognized that paraffin sections are subject to some variation in the degree of expansion during the affixing of the ribbon. In five pairs of lines the average mesophyll thickness between veinlets was 0.142 mm for the diploid and 0.199 mm for the tetraploid, an increase of 40% in thickness.

Histological differences between diploid and tetraploid roots could be recognized at an early stage of stelar differentiation. Sections in which the earliest protophloem is recognizable were arbitrarily selected for comparison. In diploid roots the cortical parenchyma consisted of four layers of cells, more or less uniform in size, with large intercellular spaces. Tetraploid cortex also consisted of four layers, but cell size varied within wider limits, numerous exceptionally large cells occurred, and the intercellular spaces were smaller (Fig. 3). No consistent differences in stelar organization of young 2n and 4n roots were observed. The vascular pattern in both 2n and 4n roots was either diarch or triarch.

CYTOLOGICAL STUDIES

The somatic chromosomes usually were well separated in the diploid metaphase figures, and the diploid number of 16 could be determined with certainty. The metaphase plate of the tetraploid complement was only slightly larger than that of the diploid, and considerable clustering and overlapping of chromosomes occurred. However, reliable counts of the 32 chromosomes of tetraploid cells were obtainable.

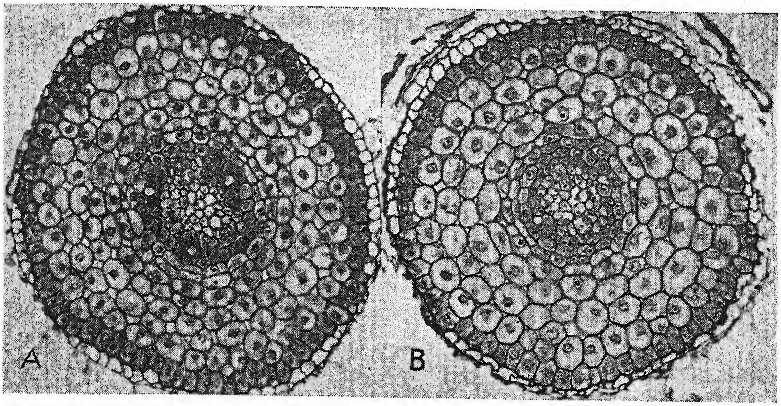


FIG. 3.—Cross sections of roots. A, diploid; B, tetraploid. 230×.

Individual chromosomes were short and compact, V-shaped at metaphase, with approximately equal arms. The arms were from 1.75 to 2.25 μ in length and 0.457 to 0.957 μ in thickness. Chromosomes of a complement differed perceptibly in size, but the differences were not readily measurable by direct micrometry.

Nuclei of tetrapoloid cells were larger than those of diploid cells. Measurements were made of late prophase nuclei because at that phase the chromosomes are peripherally distributed and sufficiently well separated to permit an estimate of the number. Diploid nuclei were found to be 8.7 to 11.0 μ in diameter, whereas tetraploid nuclei were 10.0 to 12.5 μ in diameter.

The manner in which the tetraploid condition is initiated was not ascertained in this study. Presumably, colchicine inhibits the completion of anaphase processes, thereby incorporating two sets of chromosomes into one nucleus. The establishment of the 4n condition does not take place simultaneously in all tissue systems of the root. Numerous roots having predominantly 2n tissues were found to have sectors and islands of 4n cells in the cortez. In these cases the multiplication of the larger 4n cells produces a pronounced bulge on the side of the root.

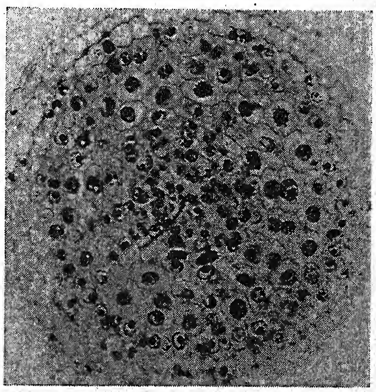


FIG. 4.—Tetraploid mitotic figures in inner layers of cortex; diploid nuclei occur in outer cortical layers and in stele. 400×.

Stelar cells retain the 2n condition longer than cortical cells, as evidenced by roots having a 2n stele encased in a predominantly 4n cortex (Fig. 4). The endogenous lateral roots arising from this type of stele would thus be 2n, thereby delaying the establishment of the 4n condition in the root system. This delay is not of

primary importance from the standpoint of the production of 4n seed. Propagation of treated plants by stem cuttings served to eliminate the residual diploid root tissues. The cytology and histology of stem apices, from which inflorescences arise, is under investigation.

The study of meiosis was designed to gain a general view of the process in the numerous tetraploid isolates. The specific correlation between meiotic behavior and fertility in selected isolates is now being studied.

Chromosome association at metaphase of the first division of meiosis was determined in anther smears. In favorable preparations the four chromatids of a bivalent are evident. However, in most preparations only the split end of each chromosome indicates the doubleness (Fig. 5A). Bivalent, trivalent, and quadrivalent associations have been observed (Fig. 5A). The numerous tetraploid lines exhibited marked differences in the extent of irregular disjunction, ranging from apparently normal distribution to a high degree of irregularity. A single lagging chromosome may be present on the spindle, or several chromosomes may be involved (Fig. 5B). The lowest number of chromosomes counted in a group at telophase was 12; the highest, 19. All intermediate distributions were observed. One line was found to exhibit no unequal chromosome distribution during meiosis.

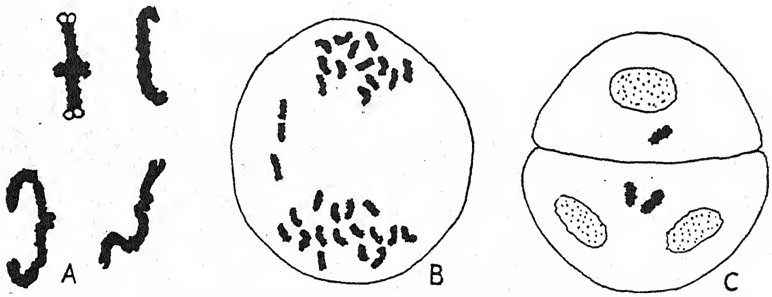


FIG. 5.—A, lagging in first division; B, anaphase lagging showing univalent, bivalent, and trivalent associations; C, excluded chromosomes in cytoplasm of early quartet.

Exclusion of chromosomes from the interphase and microspore nuclei seems to be uncommon in most lines, but it was pronounced in one line (Fig. 5C). The excluded chromosomes retain their chromaticity prior to the formation of the second cell wall, after which they are difficult to distinguish from cytoplasmic inclusions. Microspores do not exhibit distinguishable extruded chromosomes. Supernumerary micronuclei have not been observed, but their presence may well be expected in additional lines being studied.

STUDIES OF FERTILITY

A study was made under greenhouse conditions to compare tetraploid and diploid plants from non-inbred origin with respect to self-fertility, seed size, and pollen grain size. The tetraploid plants used in this study had been propagated by cuttings from the original

TABLE 1.—*Comparative self-fertility, seed size, and pollen size of autotetraploid and diploid plants of sweet clover.*

Group	No. of plants	Self fertility, per cent		Seed weight, mgm	Pollen size, microns	
		Av.	Range		Diameter	Volume
Autotetraploid......	20	7.8	0.8–18.8	2.81	35.6	23,625
Diploid.............	10	43.7	27.2–68.7	2.03	28.1	11,618
Difference (% of 2n)	..	−82.2	....	38.4	27.4	103.3

material and were pure with respect to freedom from possible diploid sectors. The data in Table 1 show a large reduction in self-fertility, and an increase in size of seed and pollen grains for the autotetraploid plants. Although the difference in average self-fertility of the 20 tetraploid plants was over 80% lower than that of diploids, a few 4n plants approached the lower limit of self-fertility of the diploids under the environmental conditions of this study. Seed weight of all tetraploid plants was large and averaged 38% above the diploids with which they were compared.

Pollen grains of 4n and 2n plants are distinctly different with respect to size, volume, and shape, and can be easily distinguished under the microscope. In all cases plants classified as tetraploids on the basis of pollen characters proved to be correct when chromosome counts were made on root tips. The average increase in pollen diameter of 27% was in good agreement with other autotetraploids as reported in the literature. The increase in pollen volume of 103% was nearly in direct proportion to the increase in chromosome number. Comparative pollen grain size and shape of diploids and tetraploids are shown in Fig. 6. The tetraploids were in all cases somewhat triangular in shape in contrast to the oval shape of the diploids.

A study was made to compare the uniformity of pollen diameters of tetraploid and diploid first-year selfed lines grown in the field. Four plants in each of four diploid and tetraploid lines were sampled by

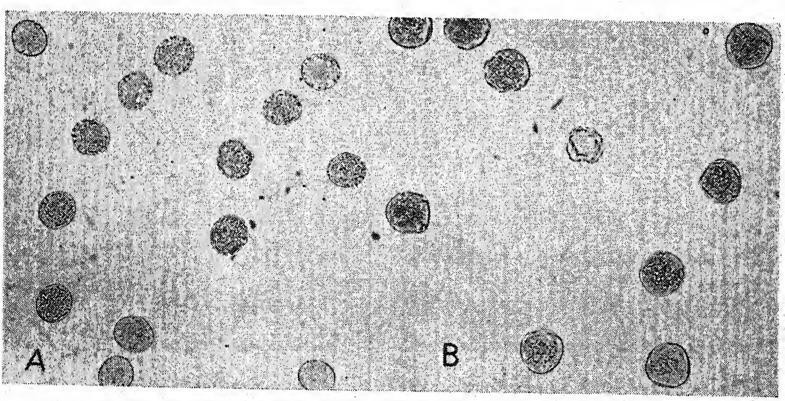


FIG. 6.—Pollen. A, diploid; B, tetraploid. 230×.

measuring 10 pollen grains on each side of two racemes. The average pollen diameters and the analysis of variance given in Table 2 show highly significant differences between the diploid and tetraploid plants. The average diameters of the two groups and the percentage increase for the tetraploids (30.1) are in very close agreement with the data obtained from the greenhouse study. Differences between lines of the diploids were not significant when tested against the variance of plants within lines, but the differences between the four tetraploid lines were highly significant, although the means varied only from 35.6 to 36.5 μ. The experimental error, using racemes as replications, was low as shown by the coefficient of variability 3.94%. The sampling error, or the variability between pollen grains from the

TABLE 2.—*Comparative pollen diameters in microns of plants in first year selfed lines of tetraploid and diploid M. alba.*

Line	Plant number 1	2	3	4	Line av.	Group av.
			Tetraploid			
101	35.8	35.7	35.8	35.5	35.7	
103	36.8	36.2	36.5	36.5	36.5	
105	35.6	36.1	36.2	35.9	35.9	
109	35.9	35.9	35.2	35.5	35.6	35.9
			Diploid			
102	27.4	27.5	27.6	27.8	27.6	
106	28.1	27.6	27.7	27.4	27.7	
111	27.5	27.5	27.6	27.4	27.5	
116	27.7	27.8	27.5	27.4	27.6	27.6

Analysis of Variance (Micrometer Units)

Source of variation	D.F.			M.S.
Total	639			
Racemes	1			0.004700
Plants	31			0.278090†
Within diploids		15		0.000693
Between lines			3	0.000600
Plants within lines			12	0.000717
Within tetraploids		15		0.002847
Between lines			3	0.009600†
Plants within lines			12	0.001158
Diploids vs. tetraploids		1		8.567700†
Exp. error	31			0.001210
Sampling error	576			0.000651
Within diploids		288		0.000566
Within tetraploids		288		0.000737*

*Exceeds the 5% level of significance.
†Exceeds the 1% level of significance.

same racemes, afforded an opportunity to compare the uniformity of pollen sizes of the two groups. The sampling error variance for the tetraploids was significantly greater than for the diploids, but because of differences between the means of the two groups, the coefficient of variability of the tetraploids was slightly less than for the diploids. It would therefore appear that in this material no real differences exist in variability of pollen diameters of diploid and tetraploid plants. This conclusion agrees with many other microscopic observations made during the period of this study. In general, pollen grains of tetraploid plants are as uniform in size and as low in aborted pollen as those from diploid plants. Differences in self-fertility between the two groups cannot be explained on the basis of pollen condition.

SELF- AND CROSS-FERTILITY OF TETRAPLOIDS

In a preliminary study made in the greenhouse during 1941–42, striking differences were obtained in cross-fertility among a group of high and low self-fertility autotetraploids. On the basis of these results, a more extensive study was made during the winter of 1942–43 to compare self- and cross-fertility in a series of paired comparisons made under comparable conditions as previously described. Eight plants were chosen from among those available, representing variations in self-fertility from nearly completely self-sterile to the maximum fertility level occurring in the entire group. Each plant was used as a female parent in four crosses. Because all four crosses per plant could not be started on the same day; a comparable raceme was also selfed for each cross made to provide an accurate basis for comparing self- and cross-fertility per plant. After all 32 crosses and 32 selfs were completed, the study was repeated approximately 1 month later, and consequently each value given in Table 4 is based on pollinations of from 80 to 100 florets. The analysis of variance was made separately on the data from each plant and the levels of significance necessary for the 5 and 1% levels were calculated to determine the significance of differences between the average fertility of the paired selfed or crossed racemes.

The average self-fertility of the eight parental tetraploid plants and the average percentage of normal pollen grains are given in Table 3.

TABLE 3.—*Average self-fertility and percentage normal pollen of plants used in self- and cross-fertility study.*

Culture No.	Average self-fertility, %	Normal pollen, %
15–2–2	19.0	99
15–4–3	18.5	97
19–2–1	11.6	99
23–2–1	8.3	87
19–1–1	3.3	97
17–1–3	1.9	96
19–3–3	0.7	93
15–1–2	0.5	93

The differences in self-fertility were highly significant when tested against the variance of plants × dates. The differences with respect to percentage of normal pollen grains were small and not significantly correlated with the percentage of self-fertility (r = .421 at 6 d.f.). It would appear that the low self-fertility of these autotetraploid plants could not be adequately explained on the basis of apparent abnormalities of the pollen grains. These results are in agreement with those reported by Fischer (3) from a study of autotetraploid lines of maize.

The cross- and self-fertility relationships among these plants as shown in Table 4 indicate some striking difference. In four of the 32

TABLE 4.—*Average cross- and self-fertility of autotetraploid plants as determined from a series of paired comparisons.*

Female parent	Male parent	Cross-fertility, %	Self-fertility female parent, %	Difference
15-2-2	17-1-3	19.0	25.5	-6.5
15-2-2	15-4-3	5.5	11.0	-5.5
15-2-2	19-2-1	32.0	16.5	15.5*
15-2-2	23-2-1	22.5	23.0	-0.5
15-4-3	15-2-2	22.5	27.0	-4.5
15-4-3	19-1-1	22.0	23.5	-0.5
15-4-3	19-3-3	4.5	7.5	-3.0
15-4-3	23-2-1	17.0	16.0	1.0
19-2-1	17-1-3	9.5	7.5	2.0
19-2-1	19-1-1	4.0	8.0	-4.0
19-2-1	19-3-3	12.5	11.0	0.5
19-2-1	23-2-1	16.5	20.0	-3.5
23-2-1	15-1-2	1.5	6.5	-5.0
23-2-1	15-4-3	4.5	7.5	-3.0
23-2-1	17-1-3	6.5	8.5	-2.0
23-2-1	19-3-3	13.5	10.5	3.0
19-1-1	15-1-2	2.5	0.0	2.5
19-1-1	15-2-2	32.0	5.0	27.0†
19-1-1	17-1-3	1.0	1.5	-0.5
19-1-1	19-2-1	28.0	6.5	21.5†
17-1-3	15-1-2	4.5	1.0	3.5
17-1-3	15-4-3	30.5	1.0	29.5†
17-1-3	19-1-1	9.5	3.0	6.5
17-1-3	19-3-3	11.5	2.5	9.0
15-1-2	15-2-2	5.0	0.0	5.0
15-1-2	15-4-3	1.5	0.0	1.5
15-1-2	19-2-1	1.0	1.0	0.0
15-1-2	23-2-1	1.5	1.0	0.5
19-3-3	15-1-2	0.0	0.0	0.0
19-3-3	15-2-2	4.0	3.0	1.0
19-3-3	19-1-1	2.0‡	0.0‡	2.0
19-3-3	19-2-1	0.0‡	2.0‡	-2.0

*Exceeds the 5% level of significance.
†Exceeds the 1% level of significance.
‡One replication only.

comparisons the percentage of cross-fertility was significantly higher than the percentage of self-fertility. Three of the four cases involved a low self-fertility female and a high self-fertility male parent, namely, 19–1–1×15–2–2, 19–1–1×19–2–1, and 17–1–3×15–4–3. This fact, however, does not necessarily indicate that the high fertility of the male parent was the major factor involved. Plants 15–2–2 and 15–4–3, the highest in self-fertility, did not give a significant increase in cross-fertility with plants 15–1–2, 23–2–1, and 19–3–3, three plants with very low self-fertility. Likewise, the low self-fertility plants when used as male parents did not significantly reduce the cross-fertility of high self-fertility female parents. As a check on possible differences in seed setting due to pollination technic, a series of paired racemes were (a) emasculated, as in crossing, and selfed with pollen from other florets on the same plant, and (b) selfed by tripping in the usual manner. The average self-fertility in six paired comparison of 6.7 and 7.0, respectively, for the two methods indicates that differences in pollination technic were not an important factor in fertility.

These results would therefore suggest that cross-compatability may be determined by factors other than those associated with the development of normal egg cells or pollen grains. These data lend support to the conclusion reached by Fischer (3) in studies with tetraploid maize that genetic factors may operate in determining the cross-fertility of autotetraploid plants. In normal diploid *M. alba* no cases of self-sterility or differences in cross-compatability have been found under controlled greenhouse conditions, where many self- and cross-pollinations have been made by the senior author. The explanation for the existence of self- and cross-sterility types in tetraploid *M. alba* cannot be made until further breeding and cytological evidence have been obtained. The genic balance concept advanced by Fischer (3) to explain the existence of cross-fertility and cross-sterility groups in the tetraploids when none exist in the diploid state may also apply in the above cases.

Preliminary data were obtained on the inheritance of high and low levels of self-fertility in a series of crosses between selected plants made in 1941–42. Regardless of the exact mechanism involved, the parental plants used in these crosses were apparently heterozygous for the factors for differential self-fertility. It should be recalled that the autotetraploid plants in this study were from an open-pollinated variety and consequently were likely to be in a heterozygous condition. The data on the self-fertility of the F_1 generation are summarized in Table 5.

In the statistical analysis of the data, racemes were used as replications. Although this error term is in reality a sampling error, its use may be justified on the basis that the plants within a particular cross were in a small compact group on the greenhouse bench and their position within the group was frequently changed to minimize possible positional effects.

In three crosses between high (15 to 20%) and low (1 to 3%) self-fertility plants, the F_1 generation plants varied significantly in fertility. Likewise in crosses between plants in which both parents were relatively high in self-fertility the F_1 plants also varied signifi-

cantly in self-fertility. Although the difference in range of self-fertility between the two groups of crosses was not large, (1.7 to 19.0 and 1.0 to 29.0, respectively) the highest self-fertility F_1 plants were obtained from the higher fertility parents. The number of crossed seeds and the population size was too small in crosses between low-fertility parents to draw definite conclusions regarding the range in self-fertility of the F_1 generation. Subsequent generations of these F_1 plants, as well as the progenies of the parents, will be studied in respect to improving their self-fertility by selection.

TABLE 5.—*Self-fertility of F_1 plants from crosses between parent plants classified as high and low in self-fertility.*

F_1 cross No.	Self-fertility of parent plants	No. of F_1 plants	Range in self-fertility	Significance of differences between plants*
15	High × Low	9	1.7–19.0	Highly significant
16	High × Low	15	2.0–13.7	Significant
17	High × Low	15	2.7–19.0	Highly significant
18	High × High	8	1.0–18.0	Significant
19	High × High	21	3.3–23.7	Highly significant
20	High × High	16	3.7–29.0	Highly significant
25	Low × Low	4	1.3–10.0	Not significant

*Highly significant and significant differences are at the 1 and 5% levels, respectively.

SUMMARY

1. Autotetraploid plants of biennial white sweet clover, *M. alba*, were produced by submerging the cotyledons and the terminal bud in 0.05% colchicine solution for 6 hours.
2. Tetraploid plants had larger vegetative and floral organs, larger leaf and root cells, and larger somatic nuclei than the diploids.
3. Periclinal chimeras and islands of tetraploid tissue occurred in the roots of treated plants. Except for cell size, histological organization of leaves and roots of diploid and tetraploid plants was identical.
4. Chromosome lagging at the first meiotic metaphase ranged from complete absence of irregularity to markedly irregular distribution. The highest number of chromosomes in a telophase group was 19; the lowest, 12. Univalent, bivalent, quadrivalent, and rare trivalent associations have been observed.
5. Pollen grains of the tetraploids were significantly larger than the diploids and were also different in shape. The uniformity of pollen grain size was not different from those of the diploids.
6. Tetraploid plants varied significantly in self-fertility, indicating a possibility of selection for higher levels.
7. Significant differences were obtained in cross- and self-fertility in 4 of 32 matings. The differences could not be explained on the basis of pollen condition or on the basis of lack of normal egg cells.
8. The F_1 generation plants, from crosses between parents differing in self-fertility, showed significant variability in self-fertility.

LITERATURE CITED

1. BERGNER, A. D., AVERY, A. G., and BLAKESLEE, A. F. Chromosomal deficiencies in *Datura stramonium* induced by colchicine. Amer. Jour. Bot., 27:676–683. 1940.
2. BRUNFIELD, ROBERT T. Cell-lineage studies in root meristems by means of chromosome rearrangements induced by x-rays. Amer. Jour. Bot., 30: 101–110. 1943.
3. FISCHER, H. E. An investigation of sterility in tetraploid maize. I. Pollen abortion. II. Incompatabilities. Doctorate thesis, Cornell University, Ithaca, N. Y. 1939.
4. MUNTZING, A. The evolutionary significance of autopolyploidy. Hereditas, 21:263–378. 1936.
5. O'MARA, JOSEPH G. Meiosis in autotetraploid secale cereale. Bot. Gaz., 104: 563–575. 1943.
6. RANDOLPH, L. F., and HAND, D. B. Increase in vitamin A activity of corn caused by doubling the number of chromosomes. Science, 87:442–443. 1938.
7. RANDOLPH, L. F. An evaluation of induced polyploidy as a method of breeding crop plants. Amer. Nat., 75:347–363. 1941.
8. SANSOME, F. W., and ZILVA, S. S. Polyploids and vitamin C. Biochem. Jour., 30:54–56. 1936.
9. SATINA, S., and BLAKESLEE, A. F. Periclinal chimaeras in *Datura stramonium* in relation to development of leaf and flower. Amer. Jour. Bot., 28: 862–871. 1941.
10. SMITH, HAROLD H. Studies of induced tetraploids of Nicotiana. Amer. Jour. Jour. Bot., 30:121–129. 1943.
11. SPARROW, A. H., RUTTLE, M. L., and NEBEL, B. R. Comparative cytology of sterile intra- and fertile intervarietal tetraploids of *Antirrhinum majus* L. Amer. Jour. Bot., 29:711–715. 1942.
12. SULLIVAN, J. T., and MYERS, W. M. Chemical composition of diploid and tetraploid *Lolium perenne* L. Jour. Amer. Soc. Agron., 31:869–871. 1939.

THE NATURE AND INHERITANCE OF STERILITY IN SWEET CLOVER, *MELILOTUS OFFICINALIS* LAM.[1]

R. E. GETTYS AND I. J. JOHNSON[2]

A KNOWLEDGE of the nature and inheritance of sterility is of fundamental importance in conducting a breeding program with a species that exhibits this character because in many cases it may limit or completely inhibit the production of inbred lines or desired crosses. In the recent trend toward forage crop improvement, compatibility relationships have received considerable attention because self-sterility is of widespread occurrence in many of these crops. Although extensive investigations have been made with several forage crops, no previous studies have been reported on the nature of the sterility mechanism in sweet clover.

The literature on self-sterility in plants is very extensive and only those papers that have a relationship to the present problem will be reviewed here. A complete survey of literature on compatibility in plants has been presented by Stout (12).[3]

The oppositional factor hypothesis was first developed and applied by East and Mangelsdorf (5) to explain the sterility found in Nicotiana. According to their hypothesis, if a pollen grain has the same sterility allele as one of those in the pistil, the resulting pollen tube fails to grow far enough in the stylar tissue to reach the micropyle. On the other hand, if the allele in the pollen grain is different from either of those in the pistil, the growth of the pollen tube is normal and fertilization may be accomplished. Sterility caused by oppositional factors has been reported in white clover by Williams (14) and Atwood (1) and in red clover by Williams (13) and Rinke and Johnson (11). The occurrence of self-fertile plants in a species that normally exhibits self-sterility has been reported in several cases. However, these self-fertile plants are relatively rare. Investigations have shown that self-fertility is due to a dominant gene in the allelomorphic series. Plants containing a self-fertility allele have been reported in red clover by Williams (13) and Rinke and Johnson (11) and in white clover by Williams (14) and Atwood (1).

The occurrence of "pseudo-compatibility" among incompatible crosses and selfs has been mentioned by all workers reporting sterility in forage species. An extensive study of pseudo-compatibility has been made by Atwood (2, 4) with white clover. In recent studies with orchard grass reported by Myers (8, 9), wide variations were found in the self-fertility of individual plants. Although different levels of self-fertility tended to be heritable, as shown by parent-progeny correlations, many of the differences were also of a nonheritable nature as demonstrated with clonally propagated plants.

In four species of sweet clover used in the breeding program in Iowa, namely, *Melilotus alba*, *M. dentata*, *M. sauveolens*, and *M. officinalis*,

[1]Contribution from the Farm Crops Subsection of the Iowa Agricultural Experiment Station, Ames, Iowa. Journal paper J.–1149, Project 152. Received for publication September 20, 1943.

[2]Graduate Student and Research Professor of Farm Crops, respectively.

[3]Figures in parenthesis refer to "Literature Cited," p. 237.

only the latter exhibits self-sterility. The fact that *M. officinalis* is not completely self-sterile has been recognized and reported by Pieters and Hallowell (10) and Kirk (6). It has been shown (6) that when the stigmatic surfaces are scratched in selfing some seed is formed, though the proportion is not so great as when the florets are open-pollinated.

MATERIALS AND METHODS

Two self-sterile and cross-fertile plants of biennial *M. officinalis* were selected at random in 1941 from a larger group grown in the greenhouse from breeding studies. These plants are designated as 20–1 and 20–2. Because of their self-sterility, the parent plants were propagated vegetatively by means of cuttings. A self-fertile inbred line of annual *M. officinalis*, culture 19–2, was crossed to one of the self-sterile plants. All plants, including parents, the F_1, and F_2, were grown under greenhouse conditions from October to June and were subjected to light from 200-watt bulbs during the night.

In making crosses, the corolla of each floret was removed with forceps and the anthers and free pollen removed by air suction. Bud emasculation was not considered desirable in making crosses between self-sterile plants because the possibility of mechanical injury to the florets would make it difficult to determine whether low seed set was due to injury or to incompatibility. The method of emasculation used in this study was similar to the "suction" method described by Kirk (7). A small glass tube was drawn out to a small bore to form a nozzle. This was connected to a small motor-driven vacuum fan by means of a rubber tube. The vacuum provided a uniform suction that could be adjusted by means of an air jet on the suction line. Enough vacuum was maintained to cause effective removal of the anthers and pollen. Pollination of emasculated florets was accomplished by tripping the desired male florets with a toothpick and rubbing the pollen-coated portion of the toothpick against the stigmas.

The florets were selfed or crossed as they progressively opened on a raceme. A period of several days was generally necessary to self or cross the desired number. The usual number of florets used on each raceme was approximately 35 and all remaining flower buds were removed before they opened.

Compatible and incompatible matings could be distinguished in 3 to 5 days after pollination. With compatible matings the ovary showed considerable enlargement and the calyx retained a normal green color, while with incompatible matings the ovary showed little or no enlargement, the calyx became light green or yellowish in color, and the florets finally fell from the raceme. By utilizing this method of detecting compatibility it was possible to plan additional matings during the optimum period of flowering.

Fertility is expressed as the percentage of florets pollinated that set normal pods. The number of pods set was used as an indication of fertility rather than the number of seeds because frequently in some plants the pods contain two seeds.

EXPERIMENTAL RESULTS

SELF-FERTILITY OF SELF-STERILE PARENTS AND THE F_1 GENERATION

At least one raceme on each F_1 plant was selfed during the period when plants were intercrossed. The racemes used as male parents for crosses were selfed in the process of tripping to obtain pollen. In cases where more than one raceme was selfed on a plant, the raceme

with the highest percentage seed set was used because that raceme was assumed to have received less mechanical injury during the process of tripping.

As shown in Table 1, considerable variation occurred in the percentage of self-fertility of the individual F_1 plants. These differences were probably due partially to environmental factors because the high fertility plants were selfed later in the season when the greenhouse temperatures were somewhat more favorable. In all cases, however, the percentage of self-fertility was distinctly lower than the cross-fertility in compatible matings, as will be shown in subsequent tables. The average self-fertility of the F_1 generation (11.1%) was not greatly different from that of the two parents.

TABLE 1.—*Self-fertility of the two self-sterile parent plants (20–1 and 20–2) and their F_1 progeny (1–1 to 1–20).*

Plant	Self-fertility, %	Plant	Self-fertility, %
20–1	7.6	1–10	6.5
20–2	10.0	1–11	6.1
		1–12	29.4*
1–1	7.2	1–13	24.6*
1–2	13.0	1–14	11.5
1–3	6.5	1–15	16.9
1–4	10.0	1–16	4.8
1–5	4.8	1–17	7.2
1–7	14.6	1–18	12.7
1–8	10.3	1–19	13.4
1–9	0.0	1–20	21.2*

*Selfs made late in the season.

Because of the rather wide differences in self-fertility between racemes on the same plants, and between plants, a study was made with the two parents to determine their variation in fertility. Three plants established from cuttings were selected, and one raceme on each plant was selfed during each of four consecutive 10-day intervals. Selfing was started during the first day of each period and continued for 4 to 5 days. All selfing was terminated on the same day to eliminate variations due to changes in environment.

The data in Table 2 show a tendency for periodic changes in self-fertility, although the differences were significant only for parent 20–1. The periods beginning January 16 and February 5 were relatively low in fertility. The position of plants on the greenhouse bench in relation to artificial light may have influenced the self-fertility values. One plant of 20–1 was directly below a 200-watt Mazda lamp and its fertility was relatively low. This factor may explain the significant differences between clonally propagated plants in this parent. These results suggest that careful control of environmental factors is essential for measurement of small differences between plants in respect to their self-fertility values.

CROSS COMPATIBILITY OF F_1 PLANTS TO BOTH SELF-STERILE PARENTS

Backcrossing the F_1 plants to both parents permits determination of the extent to which the parents differ in their sterility alleles and

TABLE 2.—*Variation in self-fertility of the two parent cultures, 20–1 and 20–2, during four consecutive 10-day intervals.*

Date	Self-fertility, %	
	20–1	20–2
Jan. 16	8.0	5.2
Jan. 26	10.0	11.4
Feb. 5	2.9	8.1
Feb. 16	9.3	15.2
Mean	7.6	10.0

Analysis of Variance

Variation due to	D.F.	Mean squares	
		20–1	20–2
Total	11	—	—
Dates	3	30.76*	57.13
Plants	2	43.88*	16.40
Error	6	5.88	24.30

*Exceeds the 5% level of significance.

also enables a separation of the F_1 plants into intra-sterile, cross-fertile groups. When the 19 F_1 plants were reciprocally backcrossed to both parents, 9 were found to be cross-fertile with parent 20–2 and cross-sterile with parent 20–1, and the other 10 were cross-fertile with both parents. These results indicated that the sterility in these plants was of the oppositional factor type and that the parents used in this cross had one sterility allele in common. Five plants were selected from each of the two groups, and these 10 plants were reciprocally backcrossed to the two parents. The parent plants were assigned definite sterility alleles, and the F_1 plants in group I and group II were also assigned definite sterility alleles on the basis of their compatibility when crossed to the parents. The number of pods set per aceme in four representative backcrosses is shown in Fig. 1.

The genotypes assigned to the two parents and the two groups of F_1 plants are given below:

Parents	Proposed genotypes	F_1 genotypes 20–2×20–1	F_1 plant numbers
20–1	S_1S_3	Group I S_1S_3	1–1, 1–4, 1–5, 1–8, 1–9
20–2	S_2S_3	Group II S_1S_2	1–2, 1–3, 1–7, 1–10, 1–19

The data in Table 3 clearly show the differential cross-fertility of the two groups of F_1 plants. The average cross-fertility of group I with parent 20–1, both designated as having the same sterility alleles, was only 8.0%, while the average cross-fertility of group I with parent 20-2, designated as having one allele in common, was 68.9%. The average cross-fertility of the F_1 plants in group II with parents

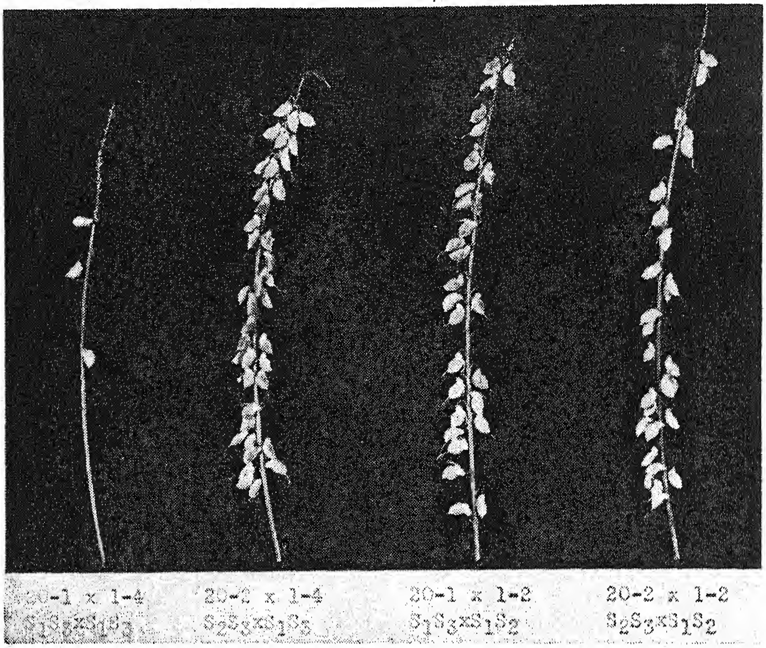


FIG. 1.—Cross-fertility of an F_1 plant in group I and group II when backcrossed to the parents.

20–1 and 20–2, where group II was designated as having one allele in common with both parents, was 74.8% and 68.9%, respectively. The

TABLE 3.—*Cross-fertility of F_1 plants reciprocally back-crossed to the parents.*

Cross	Cross-fertility, %			Cross	Cross-fertility, %		
	F_1 female	20–1 female	Av.		F_1 female	20–2 female	Av.
$(S_1S_3 \times S_1S_3)$	Group I			$(S_1S_3 \times S_2S_3)$	Group I		
1–1 × 20–1	0.0	13.9	7.0	1–1 × 20–2	86.7	76.7	81.7
1–4 × 20–1	0.0	9.7	4.9	1–4 × 20–2	56.7	85.2	71.0
1–5 × 20–1	16.0	6.7	11.4	1–5 × 20–2	40.5	76.0	58.3
1–8 × 20–1	12.9	6.1	9.5	1–8 × 20–2	69.6	58.3	64.0
1–9 × 20–1	14.8	0.0	7.4	1–9 × 20–2	51.2	88.2	69.7
Av.......	8.7	7.3	8.0	Av.......	60.9	76.9	68.9
$(S_1S_2 \times S_1S_3)$	Group II			$(S_1S_2 \times S_2S_3)$	Group II		
1–2 × 20–1	69.6	84.6	77.1	1–2 × 20–2	67.8	85.2	76.5
1–3 × 20–1	71.9	98.5	84.2	1–3 × 20–2	80.8	92.0	86.4
1–7 × 20–1	75.8	92.1	84.0	1–7 × 20–2	74.1	56.8	65.5
1–10 × 20–1	50.0	76.3	63.2	1–10 × 20–2	42.9	82.1	62.5
1–19 × 20–1	70.5	60.0	65.3	1–19 × 20–2	43.3	63.6	53.5
Av.......	67.6	81.9	74.8	Av......	61.8	75.9	68.9

wide and distinct difference in fertility of group I with the two parents justified the separation of the F_1 plants into the two proposed groups.

CROSS-COMPATIBILITY OF PLANTS WITHIN AND BETWEEN THE TWO GROUPS

To further verify the genotype of the F_1 plants separated into the two groups, each of the 10 plants was crossed with every plant in group I and group II. If the original classification was correct, crosses among plants within each group should be incompatible and crosses between plants in different groups should be compatible.

The data (Table 4) show that all plants in group I were compatible in crosses with plants in group II, thus verifying their genotypes based on the results from backcrossing to the two parents. The average fertility of all the crosses was 62.7%, and in no cases was the cross-fertility value as low as the self-fertility value of the same plant.

TABLE 4.—*Percentage cross-fertility of plants in group I (S_1S_3) with plants in group II (S_1S_2).*

Plant No.	Group II (S_1S_2)				
	1–2	1–3	1–7	1–10	1–19
Group I (S_1S_3)					
1–1	75.7	68.4	72.7	72.1	77.5
1–4	79.2	53.3	82.2	65.5	48.4
1–5	63.8	67.7	57.8	42.5	71.0
1–8	83.3	70.7	61.4	45.0	60.0
1–9	61.1	79.5	51.6	48.5	67.6

Average of all compatible crosses = 62.7%.

The final verification of the similarly of sterility alleles of plants in each of the two groups was obtained by a series of intercrosses of plants within the groups.

The results of these intercrosses (Table 5), both within group I and group II, show in all cases that the matings were incompatible. The average cross-fertility of all plants within group I was 13.5% and of all plants crossed within group II, 13.9%. The maximum cross-fertility of 27.5% (1–3×1–19) was much lower than the cross-fertility of these two plants in compatible matings. Incompatibility was expected in these crosses since all the plants within each group were shown to have identical sterility alleles on the basis of previous matings. However, as shown in Table 5, some pods were set in nearly all of the incompatible crosses. This "pseudo-cross-compatibility" was approximately equal to the "pseudo-self-fertility" values given in Table 1.

INHERITANCE OF SELF-FERTILITY

The original cross between the self-sterile plant (20–2) and plant 19–2 of the self-fertile line was made in the greenhouse in 1941–42. Seven F_1 plants were grown from this cross and were selfed during 1942–43. The clonally propagated self-sterile parent and the progeny

of the self-fertile parent were also studied during this period to allow comparison of self-fertility of the F_1 plants with that of the parents.

TABLE 5.—*Percentage cross-fertility of plants within group I and of plants within group II.*

Crosses within group I (S_1S_3)		Crosses within group II (S_1S_2)	
Plants crossed	Cross-fertility, %	Plants crossed	Cross-fertility, %
1–1 × 1–4	16.3	1–2 × 1–3	13.9
× 1–5	15.8	× 1–7	23.4
× 1–8	17.5	× 1–10	10.0
× 1–9	16.1	× 1–19	18.8
1–4 × 1–5	16.3	1–3 × 1–7	19.4
× 1–8	8.6	× 1–10	2.3
× 1–9	5.7	× 1–19	27.5
1–5 × 1–8	7.1	1–7 × 1–10	7.3
× 1–9	10.0	× 1–19	9.3
1–8 × 1–9	0.0	1–10 × 1–19	7.3
Average..........	13.5	Average..........	13.9

The F_1 plants proved to be self-fertile as shown in Fig. 2 and Table 6, indicating dominance of the self-fertility alleles (S_fS_f) carried by the self-fertile inbred parent. An F_2 population of 139 plants, grown from selfed seed of the F_1, was selfed to determine segregation for self-fertility and self-sterility. Plants of the self-sterile and of the self-fertile parent were also studied during the period when the F_2 was grown.

TABLE 6.—*Frequency distribution of percentage self-fertility of parents and of the F_1 and F_2 generation plants from the cross of 20–2 (self-sterile) × 19–2 (self-fertile).*

Pedigree	Generation	Number of plants in self-fertility classes										
		0–10	11–20	21–30	31–40	41–50	51–60	61–70	71–80	81–90	91–100	Mean
20–2	P_0	2	1	—	—	—	—	—	—	—	—	10.0
19–2	P_1	—	—	—	—	—	3	1	—	—	—	62.8
20–2 × 19–2	F_1	—	—	—	1	—	1	3	2	—	—	61.1
20–2 × 19–2	F_2	—	—	—	—	6	29	30	31	27	16	72.0

As shown in Table 6, all the F_2 plants proved to be self-fertile, and no apparent segregation occurred for self-fertile and self-sterile plants. These results are in agreement with those reported by Rinke and Johnson (11) and would indicate that in stylar tissue containing both a fertility and a sterility allele only the pollen grains with the S_f genotype are capable of normal pollen tube growth. If the pollen grains with the sterility genes (S_2 or S_3) in the heterozygous F_1 plants had been equally capable of normal pollen tube establishment, the F_2 population would have segregated in a ratio of three self-fertile to one self-sterile plant.

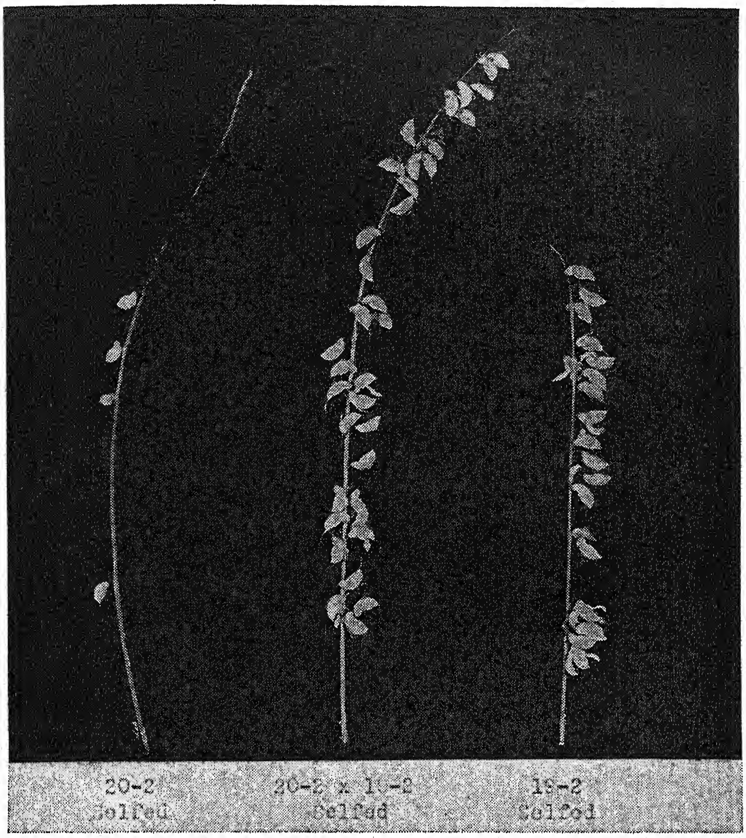


FIG. 2.—Self-fertility of the self-sterile (20–2) and self-fertile (19–2) parents and the F_1 generation.

DISCUSSION

There seems to be little doubt that sterility in *M. officinalis* is of the oppositional factor type. Among the various types of self-sterility each has definite characteristics that can be detected from a study of their breeding behavior. The data obtained from this study fit all requirements of the oppositional factor type in respect to self- and cross-fertility relationships. The difference between compatible and incompatible crosses was distinct in all cases, and little difficult was encountered in separating the plants on the basis of their sterility alleles. The characteristic for sweet clover plants to flower continuously for several months when grown in the greenhouse allowed many matings to be made on the same plant. Because pod set could be determined within a few days after making a cross, any questionable results due to adverse environmental conditions could be repeated almost immediately.

It is of interest to note that the two self-sterile parent plants, selected at random from a commercial variety, contained a sterility allele in common. This leads to a question on the extensiveness of the sterility alleles in *M. officinalis*. Very extensive series of alleles have been reported in white clover by Atwood (3) and in red clover by Williams (15). By using six plants homozygous for different sterility alleles, and by diallely crossing the other plants, all of which had one allele in common, Atwood (3) tested two series of plants in white clover. In one series, 25 of the 26 alleles proved to be different, and in the second series, 34 of the 41 alleles were different. Williams (15) in his work with red clover found 34 different sterility alleles in 20 plants studied.

The results of this study present considerable information that can be utilized in a breeding program. The introduction of the self-fertility allele into desirable plants to allow production of inbred lines can be carried out in the manner outlined by Rinke and Johnson (11). However, this method involves a considerable number of crosses and backcrosses. Sib-crossing of F_1 plants in different sterility groups has also been suggested as a method of inbreeding, but this method is slower than selfing to obtain homozygosity. The utilization of the relatively low psuedo-self-compatibility would seem to be the best solution to the problem of obtaining inbred lines in *M. officinalis*. The use of seed from incompatible selfs would also result in lines homozygous for sterility alleles. In the recombination of inbred lines to produce synthetic varieties, the amount of sib-pollination that occurs within an inbred line will adversely influence the yield of the synthetic variety. The progeny from selfed seed of a self-incompatible plant may intercross among themselves if the inbred line is not homozygous for its sterility alleles. For example, the selfed seed from a plant of the genotype S_1S_2 would produce progeny of the genotypes S_1S_1, S_1S_2, and S_2S_2. The S_1S_1 plants would be reciprocally cross-fertile with the S_2S_2 plants and S_1S_1 and S_2S_2 plants would be cross-fertile as females with the S_1S_2 plants. To insure more complete cross-pollination, each inbred line should therefore be homozygous for a different sterility allele.

SUMMARY

Two plants of biennial *M. officinalis*, selected at random, proved to be self-sterile and cross-fertile under greenhouse conditions. The F_1 progeny of these two plants were grown to study the nature of their sterility. An inbred line of self-fertile annual *M. officinalis* was also used in this study. This self-fertile line was crossed to one of the self-sterile plants and the F_1 and F_2 populations were grown to determine the inheritance of self-fertility.

The F_1 progeny from the cross of the two self-sterile plants was found to be self-incompatible. However, some pods were formed by nearly all of the plants as a result of selfing.

A study was made to determine the seasonal effect on percentage self-fertility with self-incompatible plants. The two self-sterile parents were selfed for four consecutive 10-day periods, and one

showed a significant difference in pod set while the other did not differ significantly.

When the 19 F_1 progeny of the self-sterile parents were reciprocally backcrossed to both parents, 9 were found to be cross-compatible with one parent and cross-incompatible with the other parent and 10 were cross-compatible with both parents. These results were explained by the oppositional factor type of sterility in which it was assumed that the parents had one sterility allele in common.

To further confirm this hypothesis five plants of each F_1 group were selected, and each plant was crossed in all possible combinations with plants in the same group and with plants in the other group. Crosses between plants within the same group were incompatible and crosses between plants of different groups were compatible, thus verifying the proposed genotypes.

The F_1 plants from the cross of the self-fertile line and the self-sterile plant proved to be self-fertile. An F_2 population of 139 plants was grown from the F_1 and all plants were found to be self-fertile. These results indicate that self-fertility was dominant over self-sterility, and that in the heterozygous F_1 only pollen tubes with the S_f gene are capable of penetrating the style and causing fertilization.

LITERATURE CITED

1. ATWOOD, S. S. Genetics of cross-compatibility among self-incompatible plants of *Trifolium repens*. Jour. Amer. Soc., Agron., 32: 955–968. 1940.
2. ————. Genetics of self-compatibility in *Trifolium repens*. Jour. Amer. Soc. Agron., 34:353–364. 1942.
3. ————. Oppositional alleles causing cross-incompatibility in *Trifolium repens*. Genetics, 27:333–338. 1942.
4. ————. Genetics of pseudo-self-compatibility and its relation to cross-incompatibility in *Trifolium repens*. Jour. Agr. Res., 64:699–709. 1942.
5. EAST, E. M., and MANGELSDORF, A. J. A new interpretation of the hereditary behavior of self-sterile plants. Proc. Nat. Acad. Sci., 11:166–171. 1925.
6. KIRK, L. E. Self-pollination of sweet clover. Sci. Agr., 6:109–112. 1925.
7. ————. Abnormal seed development in sweet clover species crosses—a new technique for emasculating sweet clover flowers. Sci. Agr., 10:321–327. 1930.
8. MYERS, W. M. Heritable variations in seed set under bag among plants of orchard grass, *Dactylis glomerata* L. Jour. Amer. Soc. Agron., 34:1042–1061. 1942.
9. ————. Analysis of nonheritable variations in seed set under bag among plants of orchard grass, *Dactylis glomerata* L. Jour. Amer. Soc. Agron., 34: 1114–1124.
10. PIETERS, A. J., and HOLLOWELL, E. A. Clover improvement. U.S.D.A. Yearbook, 1937: 1190–1214. 1937.
11. RINKE, E. H., and JOHNSON, I. J. Self-fertility in red clover in Minnesota. Jour. Amer. Soc. Agron., 33:512–521. 1941.
12. STOUT, A. B. The genetics of incompatibilities in homomorphic flowering plants. Bot. Rev., 4:275–369. 1938.
13. WILLIAMS, R. D. Self- and cross-sterility in red clover. Welsh Plant Breeding Sta. Bul., Ser. H, No. 12:181–208. 1931.
14. ————. Self- and cross-sterility in white clover. Welsh Plant Breeding Sta. Bul., Ser. H, No. 12: 208–216. 1931.
15. ————.Genetics of red clover and its bearing on practical breeding. Rpt. 4th Int. Grassland Congr., Aberystwyth, Wales, 238–251. 1937.

EFFECT OF PROLONGED SPRING GRAZING ON THE YIELD AND QUALITY OF FORAGE FROM WILD-HAY MEADOWS[1]

George Stewart and Ira Clark[2]

THROUGHOUT the range region of northwestern United States, the shortage of early spring feed is a major problem with stockmen. In an effort to overcome this difficulty agronomists and range technicians have suggested several modifications in management practices that would give greater forage production, each applicable to some particular area or set of conditions. This paper reports a study of prolonged spring grazing of beef cattle on wild-hay meadows, a modification not evaluated fully. It has, however, been found to be an important means of increasing both the yield and quality of forage available to cattle from a given ranch.

In the Intermountain region, early spring grazing of wild-hay meadows is common practice. Since only one hay crop is taken each season from such land, ranchmen, in order to obtain as large hay yields as possible, usually delay mowing until growth of the wild-hay grasses stops as a result of approaching maturity, or in dry years as a result of deficiency of irrigation water and low summer precipitation. Most stockmen remove their cattle from wild-hay meadows approximately 2 to 3 weeks after spring growth begins. This allows what is deemed a full growing season for the wild-hay crop, the major feed of many livestock communities (6).[3]

A few stockmen graze their hay meadows from 2 to 3 weeks longer than is the commonly followed practice. This maintains the stock in better condition until the spring growth of forage on the range is further advanced and, therefore, more capable of bearing grazing use. Stockmen who follow this practice think that hay yields are not materially, if at all, reduced by grazing the hay meadows to midspring and that such practice is profitable, but the majority of ranchers hold the opposite opinion.

The effects of prolonged spring pasturing on hay production up to the present has been largely a matter of conjecture and of argument, as no comparative grazing trials have hitherto been reported. Furthermore, it is difficult fully to appraise the effects of spring pasturing, because in order to do so the influence of this practice on the condition of livestock, the calf crop, the hay yields, and the spring range must all be properly evaluated. As one approach to this problem, a grazing trial[4] was begun in the spring of 1936 on the Circle Ranch, owned by James Jensen of Big Piney, Wyoming.[5]

---

[1]Contribution from the Intermountain Forest and Range Experiment Station, U. S. Forest Service, Ogden, Utah. Received for publication September 22, 1943.

[2]Senior Forest Ecologist and Assistant Conservationist, respectively.

[3]Figures in parenthesis refer to "Literature Cited", p. 247.

[4]This study as an "experiment" could not be made all that was desirable from a statistical standpoint. The findings are so pronounced, however, that it is thought that they have much practical value.

[5]Appreciation is expressed to Mr. Jensen for making available his ranch and cattle for this study and for cooperating wholeheartedly both in handling livestock and in general attitude.

GRAZING PLAN, MEADOW UNITS, AND METHODS

In the 600-acre meadow on the Circle Ranch made available for the study, fences enclosed two more or less typical parts, making two 36.5-acre fields designated as the north and south fields. Cattle were grazed in one of these fields only in early spring, but in the other they were allowed to graze into late spring; that is, for an additional period, which for 7 years averaged 37 days. The large meadow was grazed, as was Mr. Jensen's usual practice, into midspring, the grazing ending on the average 23 days later than on the early-grazed unit but 14 days earlier than on the meadow grazed into late spring. The durations of the grazing period varied from year to year but were roughly proportional. The utilization of the spring pasturage in the large field grazed to midspring was proportionately less intense than was the case in the two smaller fields. During 5 of the 7 years the south field was grazed into late spring and the north field only in early spring. In the other two years the treatments were reversed in order to make certain that the differences obtained resulted from the treatment and not from differences in the meadows.

The meadows used for the tests are typical of wild-hay meadows common in many parts of western United States. The plant populations are composed primarily of native species represented mainly by several sedges including Nebraska sedge, *Carex nebraskensis*; Hood sedge, *C. hoodi*; ovalhead sedge, *C. festivella*; on the drier sites Douglas sedge, *C. douglasi*, and other sedges of lesser abundance; Baltic rush, *Juncus balticus montanus*; common spike sedge, *Eleocharis palustris*; spike bentgrass, *Agrostis exarata*; bearded wheatgrass, *Agropyron subsecundum*; tufted hairgrass, *Deschampsia caespitosa*; meadow barley, *Hordeum nodosum*; foxtail barley, *H. jubatum*; and small amounts of timothy, *Phleum pratense*; and bluegrass, *Poa* spp. A relatively few broadleaf herbs, of minor importance with respect to total composition, are scattered throughout the meadows. Of these, the most abundant are common dandelion, *Taraxacum officinale*; redwool plantain, *Plantago eripoda*; elephanthead pedicularis, *Pedicularis groenlandica*; water groundsel, *Senecio hydrophilus*; cinquefoil, *Potentilla* spp; shore podgrass, *Triglochin maritima*; and seamilkwort, *Glaux* spp.

Inventories made at the time hay samples were collected show botanical composition to be fairly uniform and comparable for the three pasture units (Table 1).

TABLE 1.—*Botanical composition of the three meadows grazed to early, mid- and late spring, Big Piney, Wyoming.*

Forage plants	Percentage composition		
	North unit	West unit	South unit
Grasses	11.0	11.0	19.2
Sedges	49.4	50.8	40.3
Spikerush	13.4	8.4	12.1
Baltic rush	22.2	24.6	23.8
Broadleaf herbs	4.0	5.2	4.6

The meadows have been in irrigated wild hay for about 50 years. Although an attempt was made a few years ago to increase the proportion of redtop and timothy in the mixture, this effort was largely unsuccessful, and the plant composition is predominantly the natural one of sedges and rushes. Production of hay varies somewhat from the slightly higher ground to the swales, the yield being greater in the swales where soil is deeper and moisture conditions more favorable.

Owing to differences in seasonal growing conditions, the actual dates of grazing varied considerably from year to year during the 7 years of the test, 1936–42 inclusive. The average closing date was May 3 for the early-grazed pasture (common practice of most ranchers), May 26 for the midseason unit (representing Mr. Jensen's ordinary practice), and June 9 for the one grazed into late spring (not represented in practice). All fields were open to early spring use. The respective fields used to early, mid-, and late spring were closed at successive intervals varying with seasonal conditions, even though the duration and intensity of grazing were not constant. All units were cut for hay at about the same time, generally in late July or early August, at which time the plants in the field grazed to late spring were largely in the bloom stage and the others in early seed stages.

Hay samples from which to determine yields and chemical constituents were obtained just prior to haying by cutting 20 4×4-foot plots in each field at given intervals along two or more transect lines. All samples were harvested within a period of 48 hours. After harvest, samples were air-dried in cloth bags to approximately 6% moisture, weighed, later ground to meal fineness, and subsamples for chemical analysis drawn from each field sample. Chemical determinations were made of 4 years' data by standard laboratory methods for crude protein, ash, nitrogen-free extract, ether extract, and crude fiber. As only crude protein and ash seemed to show consistent differences, only these two constituents were determined for the 1940, 1941, and 1942 crops. Hay yields are expressed as stack-cured hay which contains approximately 15% moisture.

The effects of late season haying were studied in 1941 and 1942 by leaving plots uncut until early September. At this time hay yields were obtained and samples taken from which the protein and total ash contents were determined.

The amount of moisture available for hay production varied greatly from year to year, both in respect to irrigation water and summer storms. Irrigation water was ample in 1936, 1937, 1938, and 1942, slightly inadequate in 1939 and 1941, but definitely short in only one year, 1940. Precipitation data for Big Piney, available only since 1939, are presented in Table 2. It is obvious from the low precipitation that crop production depends largely upon irrigation. Even slight variation in the amount of irrigation water available to the growing crop is reflected in hay yields. The average acre-yields were somewhat reduced in 1939 and 1941 and very low in 1940 (Table 3), in which year growth ceased by mid-July, when the meadows were mowed for hay, in contrast with early to mid-August in other years.

TABLE 2.—*Total annual precipitation and precipitation for growing season (April, May, June, and July) at Big Piney, Wyoming, 1939–42.**

Season	1939	1940	1941	1942	Av.
Total annual	5.73	7.39	8.53	7.76	7.35
Growing season	3.50	2.19	3.49	3.91	3.27

*No record for 1936–38.

EXPERIMENTAL FINDINGS AND THEIR INTERPRETATION

The average hay yields over the 7-year period were 1.66, 1.67, and 1.46 tons per acre for the meadow units grazed to early, mid-, and late spring, respectively. The late-grazed unit thus shows a reduction of 0.20 ton per acre in comparison with the early-grazed one.

Although the exact weight of forage taken as pasturage is not known, it was approximated by allowing for the amount usually eaten by animals of known weight and age as reported in Morrison's (5) feeding standards. This calculated weight of pasturage removed was added to the weight of hay harvested, as shown in Table 3. The chemical composition of the pasturage is also unknown. As a basis for comparing the different meadows, chemical composition was assumed to be the same as that of the hay harvested. Since the percentages of crude protein and ash were most likely higher in the young plants

TABLE 3.—*Total forage production from wild-hay meadows grazed until early, mid-, and late spring and mowed for hay in late July to mid-August.**

Grazing treatment	Grazing use, animal-unit days per acre	Hay equivalent of pasturage, tons per acre	Hay yield, tons per acre	Total forage yield, tons per acre	Difference, tons per acre
			1936		
Mid.....	33.6	0.40	1.99	2.39	
Late....	44.6	0.53	1.71	2.24	−0.14
			1937		
Early...	23.8	0.28	1.85	2.13	
Mid.....	60.4	0.72	1.86	2.58	0.45
Late....	71.3	0.85	1.49	2.34	0.21
			1938		
Early...	13.5	0.16	1.84	2.00	
Mid.....	12.0	0.14	1.75	1.89	−0.11
Late....	36.2	0.43	1.62	2.05	0.05
			1939		
Early...	21.4	0.26	1.67	1.93	
Mid.....	8.9	0.11	1.73	1.84	−0.09
Late....	45.8	0.55	1.55	2.10	0.17
			1940		
Early...	0.0	0.00	1.32	1.32	
Mid.....	0.8	0.01	1.27	1.28	−0.04
Late....	39.1	0.47	1.24	1.71	0.39
			1941		
Early...	6.0	0.07	1.55	1.62	
Mid.....	8.2	0.10	1.69	1.79	0.17
Late....	16.8	0.20	1.45	1.65	0.03
			1942		
Early...	0.0	0.00	1.76	1.76	
Mid.....	1.9	0.02	1.76	1.78	0.02
Late....	22.9	0.27	1.60	1.87	0.09
			Average		
Early...	10.8	0.13	1.66	1.79	
Mid.....	15.4	0.22	1.67	1.89	0.10
Late....	38.7	0.47	1.46	1.93	0.14

*Feed consumed and hay yields are expressed as containing 15% moisture, comparable to field-stacked hay.

used for pasturage than in the hay, the assumption that it was the same is almost surely an underestimate.

In no year did the meadow grazed to late spring yield less total forage than the early-grazed. In 1936, 1937, and 1941 the pasture grazed to midspring has given slightly greater total yield than either the early- or late-grazed meadows and has averaged 0.10 ton greater yield than the early-grazed unit. In every year the late-grazed field produced a greater total yield than the early-grazed field. In 1937 the late-grazed pasture was utilized more than three times as much in spring as the early-grazed one, the respective pasturage taken being 0.28 and 0.85 ton per acre. In this year, 0.85 ton of feed was secured by grazing till late spring at a sacrifice of 0.36 ton of hay. In 1938 more than two and a half times and in 1939 more than twice as much pasturage was taken from the late-grazed meadow as from the fields grazed to early, or to midspring. In the drought year of 1940, 0.47 ton of additional pasturage was taken from the late-grazed meadow at an expense of only 0.08 ton of hay. In 1941 the meadow grazed till late spring yielded approximately three times as much pasturage as the one grazed early, and in 1942 the late unit furnished 0.27 ton of pastured forage while the early unit received no grazing use.

Hay from the field grazed into late spring was judged to be mature enough for good hay and had attained nearly maximum herbage development except in 1940 when irrigation water was short. The summary for the 7 years of the test (1936–42) given in Table 3 shows that when pasturage is added to the harvested hay, an increase in total forage yield was regularly obtained from the meadow grazed to late spring. The average total yields were 1.79, 1.89, and 1.93 tons of forage for fields grazed into early, mid-, and late spring.

FORAGE QUALITY

As common to practically all forage crops, quality of wild hay is materially affected by stage of plant maturity at harvest time. The poorest quality hay as judged by leafiness, stemminess, color, and protein content was obtained the first year of the study; that is, in 1936 when the meadows were left uncut until August 27 and 28. The best quality hay was obtained in the years 1940 and 1941, years in which the hay was cut before the grasses and sedges were fully mature. The differences in feeding value are probably best reflected in crude protein content of the wild hay (Tables 4 and 5).

The younger hay from the field grazed to late spring was highest in crude protein for every year of the seven, the averages being 8.13, 8.25, and 9.05% for the older, intermediate, and younger hay, respectively. The 7-year average acre yields of crude protein were 291.1, 311.9, and 349.3 pounds per acre from the fields grazed to early, mid-, and late spring. Expressed in relative numbers this is 100 for the field grazed to early spring, 107 for the field grazed to midspring, and 120 for the field grazed to late spring. An increase of 20% in crude protein yields is an important contribution to livestock economy. In terms of supplemental feeds, the 58 pounds per acre of additional crude protein annually for grazing to late spring is roughly

equivalent to 135 pounds of cottonseed cake or soy bean meal. At pre-war prices in this locality such an amount of cottonseed cake would cost approximately $2.70. Thus, each acre of wild-hay pasture grazed to late spring furnishes the equivalent of approximately $2.70 worth of crude protein above the hay secured from the earlier grazed meadows, and an additional value in the greater vitamin content that is known to parallel the protein content.

TABLE 4.—*Chemical analysis of hay samples collected just prior to haying from wild-hay meadows grazed to early, mid-, and late spring.**

Year	Early	Midseason	Late	Rank of late
		Crude Protein, %		
1936	—	7.49	7.61	1
1937	8.15	7.91	8.72	1
1938	7.33	7.96	9.03	1
1939	7.90	8.14	9.57	1
1940	8.69	9.51	10.14	1
1941	9.04	8.65	10.00	1
1942	7.69	8.07	8.26	1
Av.	8.13	8.25	9.05	1
		Mineral Matter, %		
1936	—	10.46	11.10	1
1937	9.96	9.70	11.04	1
1938	9.20	10.44	10.27	2
1939	8.69	9.66	10.07	1
1940	9.31	9.74	9.35	2
1941	8.71	7.85	8.54	2
1942	8.90	8.90	8.67	3
Av.	9.13	9.54	9.86	1
		Ether Extract, %		
1936	—	1.80	1.67	2
1937	1.67	1.64	1.53	3
1938	1.49	1.72	1.87	1
1939	1.64	1.98	1.73	2
Av.	1.60	1.78	1.70	2
		Crude Fiber, %		
1936	—	28.74	28.56	2
1937	30.62	31.72	30.34	3
1938	32.40	31.24	30.93	3
1939	29.95	29.84	29.60	3
Av.	30.99	30.38	29.86	3
		Nitrogen-Free Extract, %		
1936	—	51.53	51.06	2
1937	49.60	49.04	48.36	3
1938	49.58	48.66	47.92	3
1939	51.82	50.38	49.04	3
Av.	50.33	49.90	49.09	3

*Only crude protein and mineral matter analyses were made for 1940, 1941, and 1942 hay crops.

TABLE 5.—*Summary of yields of crude protein and mineral matter in hay and total forage, average of seven years, 1936–42, from fields grazed to early, mid-, and late spring.*

Meadow unit	Tons per acre	Crude protein			Mineral matter		
		%	Pounds per acre	Relative acre yields	%	Pounds per acre	Relative acre yields
				Hay			
Early	1.66	8.13	269.9	100	9.13	303.1	100
Mid	1.67	8.25	275.6	102	9.52	318.0	105
Late	1.46	9.05	264.3	98	9.86	278.0	92
				Total Forage			
Early	1.79	8.13	291.1	100	9.13	326.9	100
Mid	1.89	8.25	311.9	107	9.52	359.9	110
Late	1.93	9.05	349.3	120	9.86	380.6	116

Average mineral content gave relative acre yields of 100, 110, and 116 for total forage from the fields grazed to early, mid-, and late spring, respectively. The 16% increase in total minerals is probably also an important item in the nutrition of livestock. Since mineral content was determined as "total ash," it is not possible to separate the nutrient minerals from silica which is known to occur in wild hay in considerable quantity.

POST-SEASON CUTTING

In order to determine whether the effects of long and short periods of spring grazing on yield and quality of hay would persist late into the season, and in order to measure the effects of much delayed haying (still too common) on yield and quality, the meadows were sampled at two dates in 1941 and 1942. In each year one set of samples was taken on July 23 to 25, a few days before haying, and a second set paired with the early samples was taken on September 3, 1941, and September 9, 1942, on plots left uncut at mowing time. These data are highly pertinent, as a number of ranchers were still cutting hay or had just finished when the late samples were taken, at which time the plants had nearly ripened their seeds.

Comparative data on hay yields, crude protein, and mineral matter content of samples collected near the beginning and end of haying season, as seen in Table 6, substantiate the findings of others (1, 4, 5), showing clearly that these forage plants left in the field until past prime haying stage do not "cure on the stalk" but suffer measurable losses of important feed constituents.

During the haying season of 1941, abnormally frequent rains which delayed haying kept basal leaf growth green well into September, increasing hay yields by approximately 0.34 ton per acre, or 22%. Meantime the protein content declined by 1.70%, which is 18% of the total protein. On the meadow grazed until late spring, the decline in percentage protein was 2.61, a reduction of more than 25%

TABLE 6.—*Hay yields, crude protein, and mineral matter content of paired hay samples, one collected near beginning of haying and the second near the end of the haying season in 1941 and 1942, on fields grazed to early, mid-, and late spring.*

Meadow unit	Hay yields, tons			Crude protein, %			Mineral matter, %		
	July	Sept.	% increase	July	Sept.	% decrease	July	Sept.	% increase
				1941					
Early	1.56	1.89	21.2	9.17	7.72	15.8	8.81	9.74	10.6
Mid	1.60	1.99	24.4	8.69	7.64	12.1	7.95	9.33	17.4
Late	1.51	1.82	20.5	10.25	7.64	25.5	7.85	8.27	5.4
				1942					
Early	1.71	1.74	1.8	7.45	5.02	32.6	8.90	8.55	−3.9
Mid	1.78	1.87	5.1	7.93	4.95	37.6	8.90	9.42	5.8
Late	1.65	1.69	2.4	7.98	5.33	33.2	8.67	9.26	6.8
				Average					
Early	1.63	1.82	11.7	8.31	6.37	23.3	8.86	9.15	3.3
Mid	1.69	1.93	14.2	8.31	6.30	24.2	8.42	9.38	11.4
Late	1.58	1.76	11.4	9.12	6.48	28.9	8.26	8.76	6.1

in comparison with its content 6 weeks earlier. In 1942 with scant summer storms, hay yields gained only 0.05 ton (3%) over the 7-week period during which time protein content decreased by 35%.

Late-season cutting produced not only a low-protein, poor-quality hay, but also reduced acre yields of crude protein, as the increased yields of hay were not sufficient to offset the decline in percentage protein. On the late-grazed meadow, the yield of protein decreased 60.1 pounds an acre, or 28.9%, by being left uncut until early September, which offsets more than twofold the gain in hay yield of 11.4%. (See Fig. 1.) Increase in hay yield is of little consequence, however,

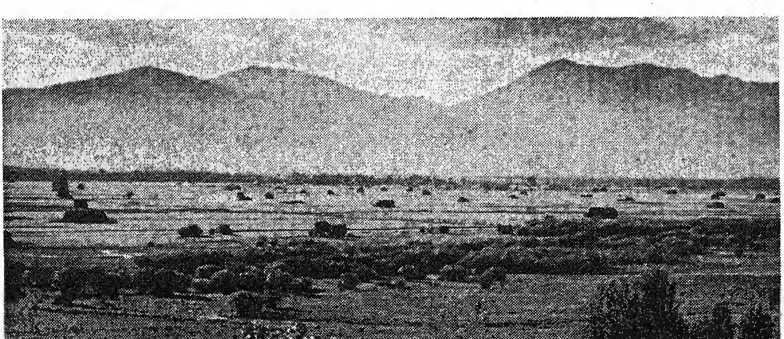


FIG. 1.—Wild-hay meadows near Jackson, Wyoming. Most of the hay is in the stack but some is still uncut (August 31, 1943) and will make poor hay because of being overmature. This is a larger tract of meadow than usually occurs in one area, but conditions throughout the Intermountain region are rather similar to those shown here.

since whatever growth occurs after cutting may be fall pastured to good advantage. It is likely, also, that the growth of aftermath would exceed the gain in weight of old hay, not to mention its higher protein and vitamin contents.

CONCLUSIONS

Conclusions that can be drawn from this field trial are of great direct importance to cattle ranchers in the West in two important respects. First, when the hay meadows are spring-pastured for 20 to 35 days beyond the usual time, the total forage yields (hay plus pasturage) are increased somewhat, and hay is so enriched in crude protein that the protein yield per acre is increased 20% over hay grown after early pasturing and 13% over that grown after pasturing to midspring. Second, wild hay deteriorates rapidly in quality when the grasses and sedges stand in the field beyond the time at which they are ready for mowing. Earlier cutting than is commonly practiced would greatly improve the quality of hay without much decreasing the hay yield. Grazing to late spring thus produces on wild-hay ranches both a somewhat greater total weight of feed, and, by having the hay younger at mowing time, produces a much higher quality in the hay. When mowing is delayed into September the proteins suffer further decreases without compensating increases in yield. The conclusion seems justified that not only may wild-hay meadows be grazed 20 to 35 days later in spring than is commonly the case, but also that the hay should be mowed as soon as it reaches the blooming period.

Moreover, the data obtained in this study indicate that the indirect off-ranch values may be as great as the improvement in the ranch-grown feed. Most cattlemen use spring and summer ranges in addition to ranch hay and pasturage. In nearly all parts of the Intermountain region, spring ranges in particular are overburdened and the forage plants are in a state of low vigor because of too early use or too heavy use, or both. Keeping a reasonable part of the cattle on the ranch for an additional 20 to 35 days results in prolonged spring grazing of the wild-hay meadows and would delay the time at which the cattle kept on the ranch went to the range and thereby reduce the intensity of grazing on the spring range. Were this practice put in operation, it would build up the range and give the stockmen, during and immediately after calving time, a chance to take better care of the cattle by having them under closer supervision than they can be given on the range.

As shown by the hay yields of the one year having short irrigation water, the assurance with which satisfactory hay yields will be obtained after grazing into comparatively late spring depends in dry years on the supply of irrigation water available somewhat late in the season. Since in the Intermountain and Northern Rocky Mountain regions irrigation water comes largely from snow in the mountains, snow surveys make it possible, and ordinarily feasible, to know the probable water supply at an earlier date than that at which grazing of the meadows needs to be discontinued.

SUMMARY

During the 7-year period, 1936–42, inclusive, three fields used for wild-hay production were grazed from beginning of growth to about May 3, May 26, and June 9. After spring grazing for the time specified in the study, the native forage plants were allowed to grow until late July or early August when all three fields were harvested for hay at about the same time. Just previous to haying, 20 4×4-foot plots in each field were harvested, all within a 48-hour period, and the forage dried to constant air-dry weight. From these samples, hay yields were calculated and samples were drawn for chemical analysis in which standard methods were used to determine crude protein and total ash. Careful records were kept as to the grazing days of each age class of cattle, from which the amount of pasturage was calculated and added to the weight of hay to get total forage yields from the three fields grazed to early, mid-, and late spring.

In the fields in which grazing was continued to late spring, the hay had a shorter growing period and decreased slightly in yield. When the pasturage taken was added to the hay, the total average forage yields were somewhat higher for the late-grazed area, being 1.79, 1.89, and 1.93 tons per acre for fields grazed to early, mid-, ond late spring, respectively.

Chemical analysis showed that for the 7 years, 1936–42 inclusive, the younger the hay, the higher the crude protein content. The crude protein percentages for the 7-year period averaged 8.13, 8.25, and 9.05 for the hay grown after early, mid-, and late grazing, respectively. The average acre-yields of crude protein were 291.1, 311.9, and 349.3 pounds an acre, which in relative numbers are 100, 107, and 120. The differences are highly reliable statistically. The relative yields for "total" mineral content were 100, 110, and 116. The total yields of protein and mineral matter were calculated on the basis that the contents of these constituents in the pasturage were the same as in the hay. The pasturage from young plants would most likely be higher in ash and definitely so in protein. Could this have been measured it would have increased still more the advantage for late grazing, as more pasturage was taken from the field that was grazed till late spring.

When haying in two years was delayed 41 and 47 days beyond the bloom period of the plants, the hay from all three meadows further deteriorated in protein content. Since the increases in yield of hay did not nearly compensate for the decrease in protein, it was concluded that it is better to cut the hay early and pasture the aftermath.

LITERATURE CITED

1. Cundy, A. T. Wyoming forage plants and their chemical composition. Studies No. 6. Wyo. Exp. Sta. Bul. 137. 1924.
2. Knight, H. G., Hepner, F. E., and Nelson, Aven. Wyoming forage plants and their chemical composition. Studies No. 2. Wyo. Exp. Sta. Bul. 70, 1906.
3. ———, ———, ———. Wyoming forage plants and their chemical composition. Studies No. 3. Wyo. Exp. Sta. Bul. 76. 1908.

4. ———, ———, ———. Wyoming forage plants and their chemical composition. Studies No. 4. Wyo. Exp. Sta. Bul. 87. 1911.
5. MORRISON, F. B. Feeds and Feeding. Ithaca, N. Y.: Morrison Pub. Co. Ed. 20. 1936. (See Table 1, pages 954–993.)
6. U. S. DEPT. OF COMMERCE. United States Census of Agriculture. Wyoming. 1935. (Page 11.)

PLANT NUTRIENT AND WATER LOSSES FROM FAYETTE SILT LOAM AS MEASURED BY MONOLITH LYSIMETERS[1]

VICTOR J. KILMER, ORVILLE E. HAYS, AND ROBERT J. MUCKENHIRN[2]

THE amounts of water and plant nutrient elements lost from the soil annually have been the subject of study and speculation for many years. Lysimeter studies of these losses have been carried on during the last two and one-half centuries (3),[3] and much information has been obtained, particularly for certain areas and conditions. There exist, however, only very limited data on water and nutrient losses from lysimeters on which runoff was permitted. Nevertheless, such data are indispensable for the satisfactory planning of measures for maximum utilization of soil, water, and fertilizers, particularly since it has been assumed that some of those measures materially increase leaching losses of plant nutrients.

The present study at the Upper Mississippi Valley Conservation Experiment Station utilized monolith lysimeters of Fayette silt loam to determine the percolation rates and plant nutrient losses from this soil when fallowed and when cropped to corn. Runoff was permitted under both crop and fallow, but measurements were also made with lysimeters under fallow when runoff was prevented.

PREVIOUS INVESTIGATIONS

The cations removed in largest amounts from the soil by leaching are calcium, magnesium, sodium, and potassium; and the anions lost in largest amounts are nitrate, chloride, bicarbonate, and sulfate (3). In general, the literature indicates that of the cations, calcium is removed in drainage water to the greatest extent. The amount of magnesium removed is usually only one third to one half as great as that of calcium. Potassium is lost to a slight extent only, usually less than 10 to 15 pounds of K_2O per acre per year under ordinary farming conditions (11), while seldom more than a trace of phosphorus is removed from the soil annually by leaching. Sulfur losses appear to vary markedly, but are comparable in amount to the magnesium loss.

Lyon, *et al.* (5) found that, with cropped Dunkirk silty clay loam at Ithaca, N. Y., the annual losses in pounds per acre were calcium, 204; magnesium, 37; potassium, 55; and sulfur, 37. These and results with other soils by the same investigators were obtained from lysimeters on which runoff was prevented so that all the precipitation was accounted for by transpiration, evaporation, and percolation. Lysimeters of the same type in other states in the humid region have usually given results similar to those reported by Lyon and his associates.

---

[1]Many of the data on nutrient losses presented in this paper constitute a portion of a thesis submitted by Victor J. Kilmer to the faculty of the University of Wisconsin in partial fulfillment of the requirements for the degree of Master of Science (Agriculture). Published with the permission of the Director of the Wisconsin Agricultural Experiment Station, Madison, Wis. Received for publication October 6, 1943.

[2]Formerly Junior Soil Surveyor, Upper Mississippi Valley Conservation Experiment Station, La Crosse, Wis.; Project Supervisor, Upper Mississippi Valley Conservation Experiment Station, La Crosse, Wis.; and Assistant Professor of Soils, University of Wisconsin, respectively.

[3]Figures in parenthesis refer to "Literature Cited", p. 263.

Stauffer (10) in Illinois has recently reported that with fallowed Tama silt loam in lysimeters allowing runoff, the loss from leaching of Ca in pounds per acre during the year ending February 28, 1939, was 47 pounds, and, during the following year, 33 pounds. Losses of Mg in pounds per acre for the same years were 27 and 16 pounds, respectively, while losses of K and S for the same periods were less than 4 pounds per acre. The Tama, although a pairie soil, was derived, like the Fayette used in this study, from loess, and under similar climatic conditions.

Considerable quantities of sulfur (4), calcium (1), and small amounts of magnesium, combined nitrogen, and other elements may be brought down in rainfall, usually as a result of their presence in smoke, soot, and dust (6). The annual removal of these elements from the soil may be largely offset by such atmospheric additions, particularly in the vicinity of industrial establishments.

The proportion of the annual precipitation lost by percolation at Ithaca, N. Y., as reported by Lyon, *et al.* (5), was 48% on cropped Dunkirk silty clay loam when runoff was prevented and when the average annual precipitation was 32 inches. Recent studies by Musgrave and Norton (9) on the Marshall silt loam, when cropped to corn at Clarinda, Iowa, show that percolation and runoff from lysimeters were 7% and 19%, respectively, on unmanured soil, and 10% and 13%, respectively, on manured soil. Stauffer (10), working with lysimeters containing fallowed Tama silt loam at Urbana, Ill., found that percolation accounted for from 3 to 25% and runoff from 17 to 29% of the average annual precipitation of 37.7 inches during the years 1936 to 1941, inclusive.

EXPERIMENTAL CONDITIONS AND PROCEDURE

SOIL AND CLIMATE

The Fayette silt loam is a member of the Gray-Brown Podzolic Group and occurs extensively in the northern portion of the Mississippi Valley. A profile of this type, as exposed near the site from which the monoliths were taken, was described by Nelson and Robertson,[4] as follows:

A_1 0–8½ inches—Dark gray silt loam with soft, floury feel.

A_2 8½–10½ inches—Grayish-brown light silt loam. The soil is phyliform and extremely friable. When pulverized, the fine crumbs yield a yellowish-brown color.

B_1 10½–15½ inches—Brown silt loam speckled with gray and dark brown spots. The soil breaks easily into small angular pieces.

B_2 15½–26 inches—Brown silty-clay loam. The soil has a nut structure that pulverizes to coarse plastic granules.

B_3 26—31 inches—Brown silt loam that breaks into angular pieces which are quite friable.

C 31–54 inches—Yellowish-brown silt loam. This loessial material breaks into large easily friable pieces which yield a distinct yellowish color when crushed.

Tables 1 and 2 present data (7) from chemical and mechanical analyses of soil from the Upper Mississippi Valley Conservation Experiment Station. Fayette silt loam, because of its high silt content, low infiltration rate, ease of dispersion, and topographical setting, is considered to be one of the most erodible soils of the United States (2, 7).

[4]NELSON, A., and ROBERTSON, A. A detail soil and erosion survey of the Upper Mississippi Valley Soil Erosion Experiment Station. Unpublished. 1934.

TABLE 1.—*pH and mechanical composition of Fayette silt loam from the Conservation Experiment Station, La Crosse, Wis.**

Depth, inches	pH	Sand, %	Silt, %	Clay, %
0–8	5.9	6.0	72.7	19.1
8–20	5.3	6.6	68.5	24.3
20–32	5.2	7.0	65.8	27.0
32–44	5.4	10.7	66.5	22.4
44–66	5.6	67.6	7.6	23.2

*After Middleton, *et al.* (7).

TABLE 2.—*Chemical composition of Fayette silt loam from the Conservation Experiment Station, La Crosse, Wis.**

Depth, inches	Percentage by weight of oven-dry soil												
	SiO_2	TiO_2	Fe_2O_3	Al_2O_3	MnO	CaO	MgO	K_2O	Na_2O	P_2O_5	SO_3	N	O.M.†
0–8.....	76.80	0.33	1.92	11.46	0.15	0.33	0.16	2.30	1.12	0.22	0.22	0.13	1.55
8–20....	75.50	0.71	3.87	11.76	0.08	1.22	0.41	2.32	1.05	0.22	0.14	0.05	0.59
20–32....	73.40	0.72	4.10	12.87	0.07	1.06	0.35	2.23	1.09	0.16	0.11	0.04	0.36
32–44....	75.10	0.72	3.70	11.85	0.07	0.94	0.26	2.58	0.89	0.19	0.03	0.03	0.28
44–66....	82.30	0.76	2.78	10.14	0.00	1.09	0.19	0.49	0.32	0.16	0.04	0.02	0.18

*After Middleton, *et al.* (7).
†O.M. = Organic matter.

The 60-year average annual precipitation for La Crosse, Wis., is 31.1 inches. About one-half of this total comes in the four months, May, June, July, and August, and nearly 70% from April to September, inclusive. The average period between killing frosts extends from May 1 to early October. The length of the growing season at La Crosse has averaged 164 days for the past 69 years. Rain storms of high intensities are common, but the total rainfall is rather uniformly distributed during the growing season. From November 15 to March 15, the soil normally is frozen, and most of the precipitation during this period is in the form of snow. The mean annual temperature is 46° F, the mean annual humidity is 82% at 6:30 a.m., and the evaporation from a free-water surface is 43.5 inches for the ice-free months of April to October. These data were obtained by the United States Weather Bureau at La Crosse, Wis.

LYSIMETER CONSTRUCTION AND TREATMENTS

The lysimeters used consisted of six metal cylinders containing Fayette silt loam profile-monoliths 36 inches in diameter and 44 inches in depth. The monoliths were encased by forcing the cylinders downward into the soil, after which they were lifted and set upon pans partially filled with gravel. The method of construction of this type of lysimeter has been fully described by Musgrave (8). The area from which the monoliths were taken had been cropped for about 50 years and was in grass at the time the lysimeters were installed.

In September, 1935, the grass and a ½-inch layer of topsoil were removed. Thereafter, until 1940, a 10% slope of the surface was maintained by annual additions of the required amount of topsoil. Lysimeters 1, 2, and 3, were cropped to corn annually, while Nos. 4, 5, and 6 were fallowed.

In 1940 the surface of each lysimeter was made as nearly level as possible and all were fallowed. Numbers 1 and 6 were enclosed so as to allow no surface runoff. These studies were continued through 1942, after which a new study was initiated.

Commencing in August, 1935, the percolate was measured in cc and weighed to the nearest 10 grams once a week, except during periods of rapid percolation when measurements were taken once a day or oftener. Runoff was measured after each runoff period. Composite samples of percolate were collected for each month during which percolation occurred, and were stored in tightly-stoppered, screw-top pint bottles.

All percolate samples which were available for the years 1937–1941, inclusive, were analyzed for calcium by titration as calcium oxalate, for magnesium by titration as magnesium ammonium phosphate, and for potassium, sulfates, and phosphorus by colorimetric methods suitable for use with small quantities of these constituents.

Six additional monoliths similar to those in the lysimeters and enclosed in cylinders, but not separated from the underlying soil, were available and were used to determine runoff from continuous, unbroken profiles. No percolate measurements could be made with these, however.

RESULTS

NUTRIENT LOSSES

Comparison of cropped and fallowed lysimeters which permitted runoff.—Calcium was lost to a much greater extent than any of the other nutrients determined (Table 3), the annual removal by leaching from soil cropped to corn being 20.6 pounds of CaO per acre and from the fallowed soil, 53.0 pounds per acre. Approximately two thirds of the loss from the cropped soil occurred during July, August, and September, but the fallowed lysimeters lost considerable amounts of calcium throughout the spring, summer, and fall.

TABLE 3.—*Losses of calcium and magnesium, expressed as the oxides, from cropped and uncropped Fayette silt loam in lysimeters which permitted runoff, 3-year average, 1937–39.*

Month	CaO, lbs. per acre		MgO, lbs. per acre	
	Cropped	Uncropped	Cropped	Uncropped
Jan.	0.0	0.5	0.0	0.3
Feb.	0.1	0.0	0.1	0.0
Mar.	0.0	1.8	0.0	0.8
Apr.	1.9	6.1	0.8	2.6
May	0.1	6.8	0.1	4.0
June	0.6	2.5	0.3	1.4
July	6.3	6.1	2.5	2.3
Aug.	5.0	4.6	2.2	2.3
Sept.	2.7	5.3	1.2	3.8
Oct.	0.9	8.6	0.2	5.9
Nov.	3.0	10.7	2.2	7.4
Dec.	0.0	0.0	0.0	0.0
Total	20.6	53.0	9.6	30.8

The annual loss of magnesium, in terms of MgO, was 9.6 pounds per acre from cropped soil and 30.8 pounds per acre from uncropped soil. The ratio of magnesium-oxide to calcium-oxide in the leachate from cropped soil was 1:2.

The annual loss of potassium was negligible, being only 0.5 pound of K_2O per acre from cropped soil and 1.4 pounds per acre from fallowed soil (Table 4). Monthly losses varied from a trace (less than 0.01 pound K_2O per acre) to 0.3 pound per acre; the highest losses from the cropped lysimeters occurred during July and August. The rate of leaching from the fallowed lysimeters was quite uniform from the month of June through the month of November. Little potassium was removed during the spring and winter periods.

TABLE 4.—*Losses of potassium and sulfur, expressed as oxides, from cropped and uncropped Fayette silt loam in lysimeters which permitted runoff, 3-year average, 1937–39.*

Month	K_2O, lbs. per acre		SO_3, lbs. per acre	
	Cropped	Uncropped	Cropped	Uncropped
Jan.	0.00	Trace	0.00	0.19
Feb.	0.01	0.00	0.13	0.00
March	0.00	0.03	0.00	0.20
Apr.	Trace*	Trace	0.11	0.59
May	Trace	0.09	0.02	0.75
June	0.02	0.22	0.15	0.42
July	0.17	0.26	0.42	0.55
Aug.	0.14	0.13	0.39	0.57
Sept.	0.09	0.22	0.38	1.03
Oct.	Trace	0.23	Trace	1.28
Nov.	0.09	0.26	0.41	1.58
Dec.	0.00	0.00	0.00	0.00
Total	0.52	1.44	2.01	7.16

*Trace = Less than 0.01 pound per acre.

The loss of sulfur, expressed as SO_3, from Fayette silt loam was found to be small, although about four times as great as potassium oxide. The cropped soil lost 2.1 pounds per acre and the uncropped soil 7.2 pounds per acre per year. About 80% of the annual sulfur losses from the cropped soil occurred during the summer and fall periods. The highest monthly losses from the uncropped soil occurred during September, October, and November, with over 50% of the annual loss being accounted for during these 3 months (Table 4).

An occasional trace of phosphorus was found in the percolate, but the amount was too small to be readily determined. The loss of this constituent in the drainage water from Fayette silt loam is undoubtedly insignificant.

Relation of concentration and volume of percolate to monthly nutrient losses.—Data represented in Figs. 1 and 2 showing the relation of the volume of water passing through the soil mass to the concentration and to the total quantity of the calcium, expressed as CaO, in the drainage water. It is evident that leaching losses of calcium were large-

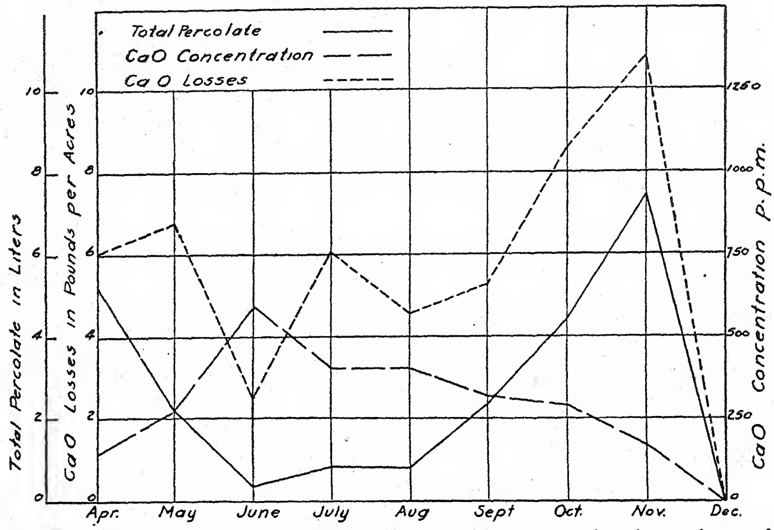


FIG. 1.—Calcium losses from triplicate fallow lysimeters as related to volume of percolate and CaO concentration, averages for 1937–39, inclusive.

ly dependent upon the amount of percolation taking place. In general, these lysimeter results indicate that the concentration of calcium in drainage waters was higher from cropped than from fallowed soil.

Magnesium and sulfur losses also are influenced to a large extent by the amount of percolation taking place through the lysimeter profile. While the concentration of these constituents in the drainage waters is lower during periods of greatest percolation, the concentration does not decrease as much, proportionately, as the rate of percolation increases, so the total loss under any condition is determined largely by the amount of percolate.

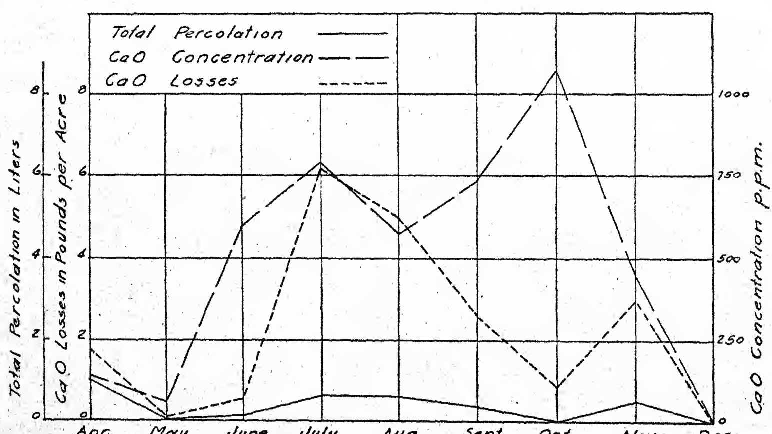


FIG. 2.—Calcium losses from triplicate lysimeters cropped to corn as related to volume of percolate and CaO concentration, averages for 1937–39, inclusive.

Comparison of fallowed lysimeters with, and without, runoff.—Runoff was prevented in lysimeters 1 and 6 during 1940 and 1941, hence the precipitation on these lysimeters either entered the soil profile or evaporated. Lysimeters 2, 3, 4, and 5 permitted runoff to occur as in previous years. All lysimeters were fallowed during 1940 and 1941, and the surface of each was made as nearly level as possible.

Leaching losses from lysimeters which permitted no runoff were two to four times greater than from those on which runoff was permitted (Table 5).

TABLE 5.—*Losses in terms of the oxides of calcium, magnesium, sulfur, and potassium in drainage water from fallowed lysimeters with and without runoff during 1940 and 1941.*

Lysimeter	Lbs. per acre, 1940				Lbs. per acre, 1941			
	CaO	MgO	SO_3	K_2O	CaO	MgO	SO_3	K_2O
				With Runoff				
2 and 3*....	14.9	6.8	1.0	0.4	119.1	44.0	24.7	1.7
4 and 5†....	22.9	10.1	4.0	0.5	92.6	38.4	15.6	1.4
				Without Runoff				
1*.........	29.0	20.2	8.6	1.3	149.6	53.0	35.3	4.8
6†.........	78.0	43.8	13.5	1.4	171.2	87.0	29.9	2.9

*Planted to corn 1936–9.
†Continuously fallowed.

WATER LOSSES

Comparison of cropped and fallowed lysimeters which permitted runoff.—The amounts of percolation, runoff, and "vapor loss" which occurred from cropped and fallowed lysimeters during 1936 to 1939 are given in Table 6. The term "vapor loss" refers, with fallowed lysimeters, to water which evaporated from the soil; with cropped lysimeters, it refers to the water which evaporated from the soil plus that which was transpired from the corn. Such water, of course, may have been temporarily stored in the soil. The vapor loss was calculated by subtracting the sum of runoff plus percolate from total precipitation.

Drifted snow occasionally accumulated on the lysimeters during winter storms. When the drifted snow melted during a subsequent thaw or simultaneous rain and thaw, runoff in excess of measured precipitation occurring during winter snows and rains sometimes took place. When such excess runoff was observed, it was assumed that the vapor loss from the soil was zero.

During the 4-year period, on the average, 20.5 inches of rain were absorbed by the cropped lysimeters; the remaining 11.5 inches ran off. Of the 20.5 inches absorbed, only 0.2 inch appeared as percolate. The remaining 20.3 inches were evaporated and transpired into the air. Corn and fallow, under the conditions of these experiments, allowed somewhat more than one third of the average annual rainfall to be lost as runoff.

TABLE 6.—*Disposition of precipitation in lysimeters, 1936–39.*

Year	Precipitation, inches	Runoff		Absorbed by soil*		Percolation		Vapor loss	
		Inches	%	Inches	%	Inches	%	Inches	%
				Fallow					
1936	27.9	11.6	41.5	16.3	58.4	0.4	1.4	15.9	57.0
1937	30.0	9.2	30.7	20.8	69.3	1.3	4.3	19.5	65.0
1938	45.8	19.5	42.6	26.3	57.4	2.1	4.6	24.2	52.8
1939	24.5	10.8	44.1	13.7	55.9	1.0	4.1	12.7	51.8
4-yr. av.	32.0	12.8	40.0	19.3	60.3	1.2	3.8	18.0	56.2
				Corn					
1936	27.9	8.9	31.9	19.0	68.1	0.4	1.4	18.6	66.7
1937	30.0	7.8	26.2	22.1	73.7	0.1	0.4	22.0	73.4
1938	45.8	19.6	42.8	26.2	57.2	0.2	0.4	26.0	56.8
1939	24.5	9.8	40.0	14.8	60.4	0.3	1.2	14.5	59.0
4-yr. av.	32.0	11.5	36.0	20.5	64.1	0.2	0.8	20.3	63.4

*Total precipitation minus runoff.

On the fallowed lysimeters, the amount absorbed by the soil was 1.2 inches less than on the cropped lysimeters but the amount of "vapor loss", in the absence of a crop, was 2.3 inches less. Percolation, however, was six times greater with fallowed lysimeters, although it totaled only 1.2 inches, or less than 4% of the annual rainfall. Percolation from fallowed lysimeters was not much greater than that from cropped lysimeters in dry years; but in years of normal or abundant rain it was as much as 10 times greater.

There was no significant difference in the amount of percolate obtained from the cropped and fallowed lysimeters during 1936. The influence of the grass growing on the lysimeter soils previous to September, 1935, may have been responsible for this result.

Runoff from the lysimeters cropped to corn was less than that from fallowed lysimeters, the greatest difference occurring during 1936. During 1938, however, when several severe storms occurred, the runoff from the cropped and fallowed lysimeters was approximately the same.

Comparison of fallowed lysimeters with and without runoff.—During 1940–41, two lysimeters (1 and 6) were enclosed so as to prevent runoff. All lysimeters were fallowed and cultivated to control weeds.

The lysimeters on which runoff was prevented had from two to four times as great a percolation loss as lysimeters allowing runoff (Table 7). The lysimeters without runoff, on which all of the rainfall was forced to pass into the soil profile, frequently had from 1 to 2 inches of water ponded on the soil surface after heavy rains. That is, of course, an abnormal condition for sloping upland soils such as the Fayette.

Maximum rates of percolation.—A recording rain gage was placed under various lysimeters during 1936 to 1941, thus making it possible

TABLE 7.—*Disposition of precipitation in fallow lysimeters with and without runoff.*

Lysimeter No.	Year	Runoff		Absorbed by soil		Percolation		Vapor loss	
		Inches	%	Inches	%	Inches	%	Inches	%
With Runoff									
2 and 3*	1940	8.5	26.6	23.5	73.4	0.4	1.2	23.1	72.2
2 and 3	1941	11.7	30.5	26.7	69.5	6.1	15.9	20.6	53.6
4 and 5†	1940	9.4	29.3	22.6	70.6	1.2	3.8	21.4	66.9
4 and 5	1941	12.2	31.7	26.2	68.2	4.4	11.4	21.9	57.0
Av. 2, 3, 4, and 5		10.5	29.7	24.7	70.3	3.0	8.5	21.7	61.8
Without Runoff									
1*	1940	0	0	32.0	100.0	1.8	5.6	30.2	94.4
1	1941	0	0	38.4	100.0	11.2	29.2	27.2	70.8
6†	1940	0	0	32.0	100.0	4.1	12.8	27.9	87.2
6	1941	0	0	38.4	100.0	11.8	30.7	26.6	69.3
Av. 1 and 6.....		0	0	35.2	100.0	7.2	20.5	28.0	79.5

*Planted to corn 1936–39.
†Continuously fallow 1936–41.

to obtain a graphic record of percolation. The percolation rate from those lysimeters which permitted runoff was very low, the maximum observed being at the rate of 0.04 inch per hour for a 20-minute period. During 1941 a recording rain gage was placed under lysimeter No. 6 (no runoff permitted) and some excellent charts were obtained. Rates of percolation measured in this manner are shown in Figs. 3 and 4. The characteristics of the rainfall occurring during the two periods are given in Table 8.

TABLE 8.—*Characteristics of rains occurring September 15–16, and October 31–November 1, 1941.*

Period of rainfall			Total, inches	Maximum intensities, inches per hour			
Start	End	Duration		5 min.	15 min.	30 min.	60 min.
Sept. 15: 7:46 p.m.	Sept. 16: 1:30 a.m.	5 hrs., 44 min.	2.63	4.32	3.44	2.24	1.67
Oct. 31: 12:40 p.m.	Nov. 1: 8:56 a.m.	20 hrs., 16 min.	1.43	0.79	0.40	0.40	0.36

As shown by Fig. 3, the rate of percolation followed the precipitation pattern rather closely. Rapid percolation began about 4 hours after precipitation started. The increase in the percolation rate was extremely sharp. This peak rate of flow was maintained for a very

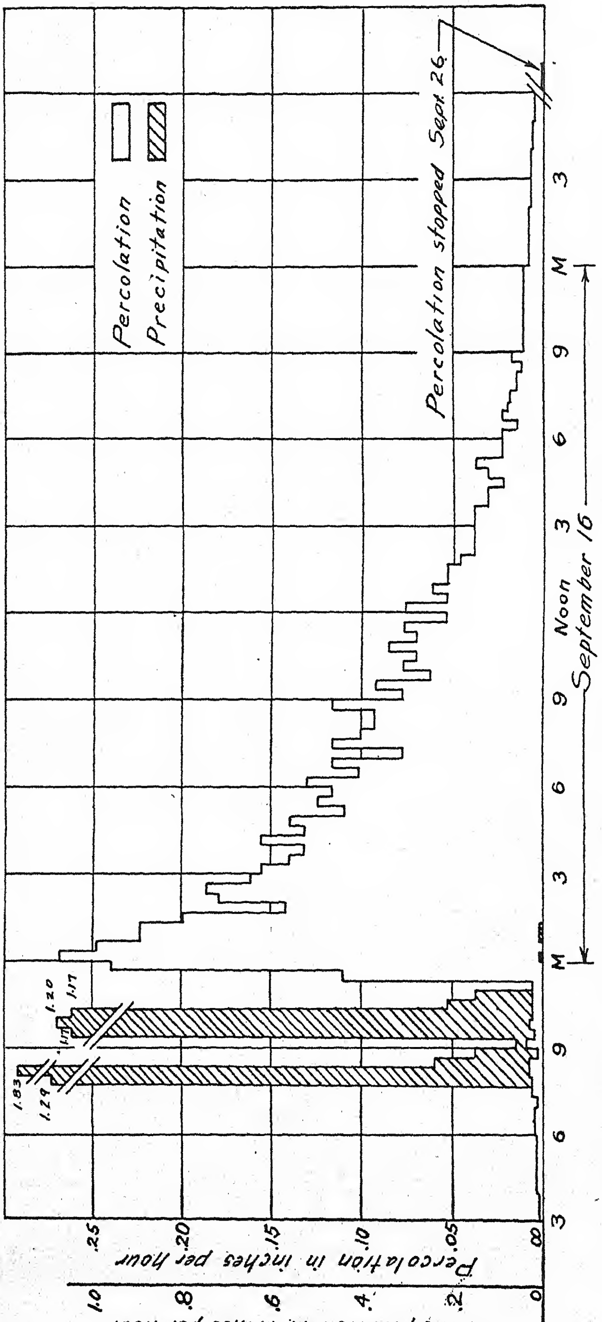


FIG. 3.—Precipitation and percolation rates from lysimeter No. 6 for storm of September 15–16, 1941.

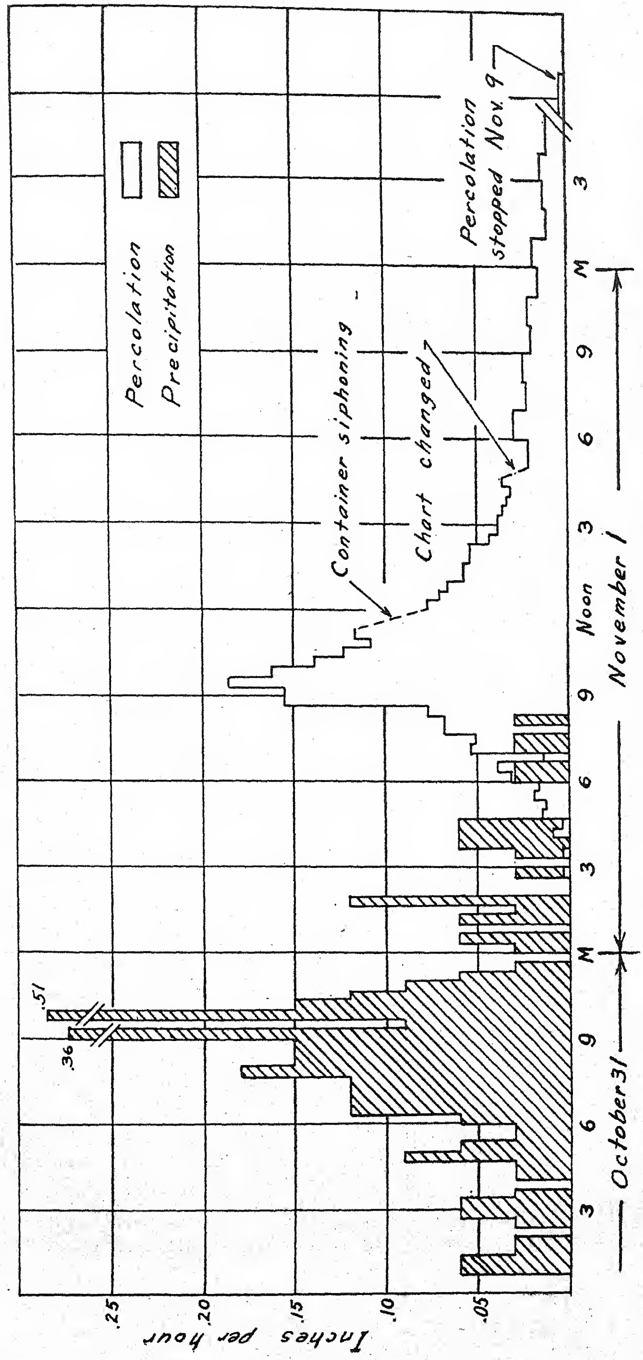


FIG. 4.—Precipitation and percolation rates from lysimeter No. 6 for storm of October 31 to November 1, 1941.

short period of time, after which the rate of flow decreased somewhat irregularly. The maximum rate of percolation, 0.26-inch per hour, observed about 4 hours after the highest rate of precipitation was reached, is in rather good agreement with the infiltration rate of 0.35-inch per hour, observed on Fayette silt loam by Free, Browning, and Musgrave (2).

Fig. 4 gives the rates of percolation prevailing when rainfall of long duration and low intensity occurred. The pattern of percolation is similar to that shown in Fig. 3, except that the maximum rate of percolation is lower and the increase in the rate of flow, first evident about 14 hours after precipitation started, is not as sharp.

Comparison of runoff from a continuous soil profile with that from a lysimeter.—Questions have been raised as to whether or not normal drainage conditions can exist in a lysimeter, which of necessity, is separated from the soil underneath. While the difference, if any, in percolation between lysimeters and continuous soil blocks could not be determined with the equipment available, it was possible to compare the amount of water absorbed by soil monoliths having a continuous soil profile (no drainage pans) with that absorbed in lysimeters with a soil profile that was not continuous (having drainage pans). This was accomplished by measuring the amount of runoff from these two types of installations (Table 9).

TABLE 9.—*Amount of surface runoff and water absorbed by monoliths having a continuous profile and by lysimeters having drainage pans, average of three lysimeters, 1936–39, inclusive.*

Year	Precipitation, inches	Corn				Fallow			
		Continuous profile		With pan		Continuous profile		With pan	
		Runoff, inches	Absorbed by soil, inches	Runoff, inches	Absorbed by soil, inches	Runoff, inches	Absorbed by soil, inches	Runoff, inches	Absorbed by soil inches
1936	27.9	11.1	16.8	8.9	19.0	11.7	16.2	11.6	16.3
1937	30.0	7.7	22.2	7.8	22.2	7.3	22.6	9.2	20.8
1938	45.8	17.1	28.7	19.6	26.2	17.3	28.5	19.5	26.3
1939	24.5	8.2	16.3	9.8	14.7	7.8	16.7	10.8	13.7
4-yr. av.	32.0	11.0	21.0	11.5	20.5	11.0	21.0	12.8	19.2

Little difference in the amount of runoff and the amount of water absorbed was found between soil monoliths having a continuous profile and those having drainage pans. The monoliths without drainage pans had slightly less runoff and, consequently, slighter greater absorption than the monoliths (lysimeters) having drainage pans. This slightly greater absorption would have but little effect upon the amount of percolation occurring.

DISCUSSION

Calcium and magnesium losses by leaching are of minor importance in Fayette silt loam when a crop is grown, and they are small even under fallow. When runoff was prevented on this soil, leaching losses were increased two-to-four-fold, but the total loss was still relatively small. For example, Fayette silt loam, without either runoff or crop during 1940 and 1941 (Tables 3 and 5), lost only 86 pounds more CaO per acre per year from leaching than with both runoff and crop during 1937 to 1939, inclusive. Nutrient loss data from other lysimeters under uniform treatment during these two periods show that these periods are comparable. The loss of MgO was increased only 41 pounds per acre per year in the absence of crop and runoff, so that the total calcium and magnesium losses, even from *fallow soil without runoff*, could have been corrected by an annual addition of approximately 300 pounds of dolomitic limestone or a total of only 1½ tons in 10 years.

Potassium, phosphorus, and sulfur losses are negligible with Fayette silt loam both under corn and under fallow. Even complete prevention of runoff combined with fallowing did not raise potassium and phosphorus losses significantly or increase sulfur losses seriously.

Nitrogen losses may be considerable from fallowed prairie soils, as shown by Stauffer (10). He suggests that increased percolation might produce large losses by leaching, so that mechanical water-retaining measures may be objectionable. Unfortunately, losses of combined nitrogen were not determined with the Fayette silt loam, but it is unlikely that nitrate losses would be large with this soil because the total amount of percolation is so small under a crop, i.e., about 1% of the annual precipitation when runoff is permitted.

This study has shown that the losses of calcium, magnesium, potassium, phosphorus, and sulfur would be comparatively small on Fayette soil even if runoff were prevented. Soil and water-conserving practices, therefore, would not materially increase the leaching losses of these nutrients, and probably not of nitrates.

The amount of water lost by percolation from the Fayette silt loam on a 10% slope is very small when runoff is permitted, amounting to less than 4% of the annual precipitation with fallowed lysimeters, and less than 1% with lysimeters cropped to corn during the 4 years 1936–39, inclusive. In 1940 and 1941, when the plot surface was maintained at approximately a zero slope, the loss of water by percolation from fallowed lysimeters was 9% and 20% when runoff was permitted and prevented, respectively. The water losses under the fallowed conditions recorded above are similar to those reported by Stauffer (10) with various prairie soils under similar climatic and experimental conditions.

The amounts of runoff and percolate from the monolith lysimeters are very similar to those from larger lysimeters operated by the U. S. Forest Service at La Crosse, Wis. These larger units are 20 feet long, 10 feet wide, and 44 inches deep, and were filled with blocks of Fayette silt loam. A slope of 10% has been maintained on the surface of the soil in these lysimeters. This slope is the same as that on the monolithic units used in this study during the years 1937–39.

Unpublished data obtained by the Forest Service[5] during the period May, 1936, to May, 1942, showed that the following percentages of the annual precipitation were lost as runoff and percolate, respectively: corn, 26 and 1.6%; barley without legume seeding, 26 and 0.7%; bluegrass sod, 6 and 8%; young hardwood trees, artificially mulched, 7 and 15%; and young Scotch pines, artifically mulched, 6 and 5%.

The runoff from the monolith lysimeters was also similar to that from 1/100-acre plots on a 16% slope. During the period 1936 to 1938, the average annual runoff from such a plot cropped to corn was 37.2% in comparison with 35.0% from the monoliths cropped to corn. Under fallow during the same period, the 1/100-acre plot lost 36.8% runoff, while the monoliths lost 38.8%. It is clear, therefore, that the runoff from the monolith lysimeters was not essentially different from that occurring on larger plots on a 16% slope. The presence of drainage pans under the monoliths appeared to have little effect on the amount of runoff occurring at the soil surface. This is confirmed by the data in Table 9 which show little difference in runoff between monoliths with and without drainage pans.

Data from La Crosse, Wis., and elsewhere show that strip-cropping and terracing do not reduce, to any great extent, the total amount of runoff from a particular crop under field conditions. Strip cropping and terracing decrease soil losses by preventing the concentration and reducing the velocity of runoff waters rather than by reducing the total volume of runoff. However, dense crops, such as hay, allow less than one half as much runoff as intertilled crops so that rotations which include hay and grass reduce the average annual runoff markedly. For example, three watersheds, each from 3 to 5 acres in area and devoted to a rotation of crops, have been treated as follows: One was farmed as a field without strip cropping or terracing, the second was strip cropped, and the third was terraced. The average annual runoff from these watersheds for the 5-year period 1937 to 1941 was without strip cropping or terracing, 2.58 inches; strip cropped, 2.37 inches; terraced, 3.36 inches. Such a variation, about 1 inch per year, in total runoff probably would have but little effect on the amount of plant nutrient content of the percolate. In this investigation, nutrient losses were small even when runoff was entirely prevented.

SUMMARY

The results of a 6-year lysimeter study on Fayette silt loam are presented. The lysimeters consisted of cylindrical soil monoliths, 36 inches in diameter and 44 inches deep. Runoff was permitted on some of these units and some were cropped to corn while others were fallowed.

The plant nutrients determined in the percolate, when arranged in order of decreasing amount of loss by leaching, were as follows: Calcium, magnesium, sulfur, potassium, and phosphorus. Losses by leaching were small even when at their maximum as a result of fallowing and the prevention of runoff. During a 3-year period when runoff was permitted, cropped lysimeters lost an annual average of 21 pounds

[5]BATES, C. G. Lake States Forest Experiment Station. 1943.

of calcium oxide per acre, while, under fallow conditions, they lost 53 pounds per acre per year. Annual magnesium oxide losses were 10 and 31 pounds per acre from cropped and fallowed lysimeters respectively. The annual loss of sulfur, in terms of SO_3, was found to be 2 pounds per acre from cropped lysimeters, and 7 pounds per acre from uncropped lysimeters. Potassium oxide and phosphorus losses were negligible. Plant nutrient losses from fallowed lysimeters which permitted no runoff were found to be two to four times as great as from fallowed lysimeters which permitted runoff.

Lysimeters with a 10% slope planted to corn and permitting runoff lost an average of 0.8% of the precipitation by percolation, while similar fallowed lysimeters lost 3.8%. With fallowed lysimeters during 1940 and 1941, water loss by percolation when runoff was prevented averaged 20% of the precipitation; when runoff from a level surface was permitted, it averaged about 9%. The maximum rate of percolation from a fallowed lysimeter permitting no runoff was observed to be 0.26 inch per hour; with runoff, 0.04 inch per hour.

No significant difference in surface runoff was noted between soil monoliths having a continuous soil profile and lysimeters having drainage pans. The amount of water intake into the soil with these two types of installations was, therefore, nearly equal in amount.

Soil and water conserving practices apparently do not seriously increase leaching of plant nutrients under soil and climatic conditions similar to those prevailing with the Fayette silt loam.

LITERATURE CITED

1. ELLETT, W. B., and HILL, H. H. The effects of certain lime materials on the leachings from Frederick silt loam soil. Va. Agr. Exp. Sta. Tech. Bul. 61. 1937.
2. FREE, G. R., BROWNING, G. M., and MUSGRAVE, G. W. Relative infiltration and related physical characteristics of certain soils. U.S.D.A. Tech. Bul. 729. 1940.
3. KOHNKE, H., DREIBELBIS, F. R., and DAVIDSON, I. M. A survey and discussion of lysimeters and a bibliography on their construction and performance. U.S.D.A. Misc. Pub. 372. 1940.
4. LYON, T. L., and BIZZEL, J. A. Composition of drainage water from lysimeters at Cornell University. Proc. and Papers, 1st Int. Cong. of Soil Sci., 2:342–357. 1927.
5. ————, ————, WILSON, B. D., and LELAND, E. W. Lysimeter experiments—III. Cornell Univ. Agr. Exp. Sta. Mem. 134. 1930.
6. MACINTIRE, W. H., and YOUNG, J. B. Sulfur, calcium, magnesium, and potassium content and reaction of rainfall at different points in Tennessee. Soil Sci., 15:205–227. 1923.
7. MIDDLETON, H. E., SLATER, C. S., and BYERS, H. G. The physical and chemical characteristics of the soils from the erosion experiment stations. Second report. U.S.D.A. Tech. Bul. 430. 1934.
8. MUSGRAVE, G. W. A device for measuring precipitation waters lost from the soil as surface runoff, percolation, evaporation, and transpiration. Soil Sci., 40:391–401. 1935.
9. ————, and NORTON, R. A. Soil and water conservation investigations at the Soil Conservation Experiment Station, Missouri Valley Loess Region, Clarinda, Iowa. Progress Report, 1931–35. U.S.D.A. Tech. Bul. 558. 1937.
10. STAUFFER, R. S. Runoff, percolate, and leaching losses from some Ilinois soils. Jour. Amer. Soc. Agron., 34:830–835. 1942.
11. TRUOG, E., and JONES, R. J. Fate of soluble potash applied to soils. Ind. and Eng. Chem., 30:882–885. 1938.

NOTES

A MACHINE FOR DEHULLING OATS[1]

IN connection with such experiments as testing oats for smut, or determining the amount of hull and groats, it is desirable to have a convenient method of dehulling the seeds. Different methods have been used, such as running the oats through a small head thresher which has been geared rather high. While this method removes the hulls fairly satisfactorily, it is likely to injure many of the kernels. The method of removing the hulls by hand has been followed, but this is a rather tedious and difficult process and is not very practical, particularly during the present shortage of labor.

In connection with experiments conducted by the Department of Plant Breeding at the Cornell University Agricultural Experiment Station, Ithaca, N. Y., it seemed worth while to design a machine for dehulling oats. One of our experimentalists, George H. Willis, in cooperation with L. H. Scott, worked on this problem and they have developed a machine which has proved very satisfactory. The machine is approximately 12 inches by 6 inches by 4 inches, and consists of two rollers made of old steel drill ends set very close together, operated by a set of gears and run by a small electric motor. By controlling the speed it is possible to dehull oats satisfactorily. It requires much less time than to dehull by hand and the work is much easier.

Views of the machine are shown in Figs. 1 and 2. In Fig. 1, the rollers are shown, and also the container which catches the dehulled kernels. This container is easily removed to transfer the kernels into

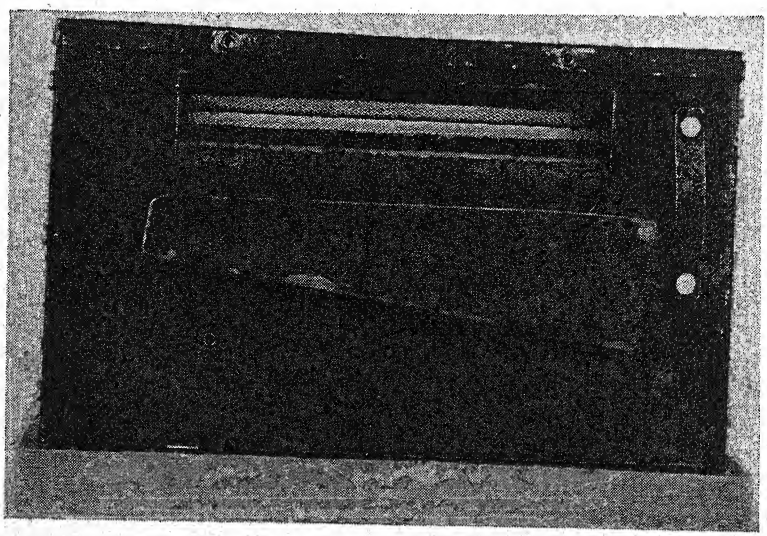


FIG. 1.—Machine for dehulling oats.

[1]Paper No. 242, Department of Plant Breeding, Cornell University, Ithaca, N. Y., in cooperation with the Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture.

envelopes or boxes. The hulls pass on through the rollers and drop into the machine. It is necessary to empty these from time to time. A view of the interior of the machine is shown in Fig. 2. Here the front, top, and ends have been removed, showing the gears and small motor and giving a better idea of the general plan of the machine.

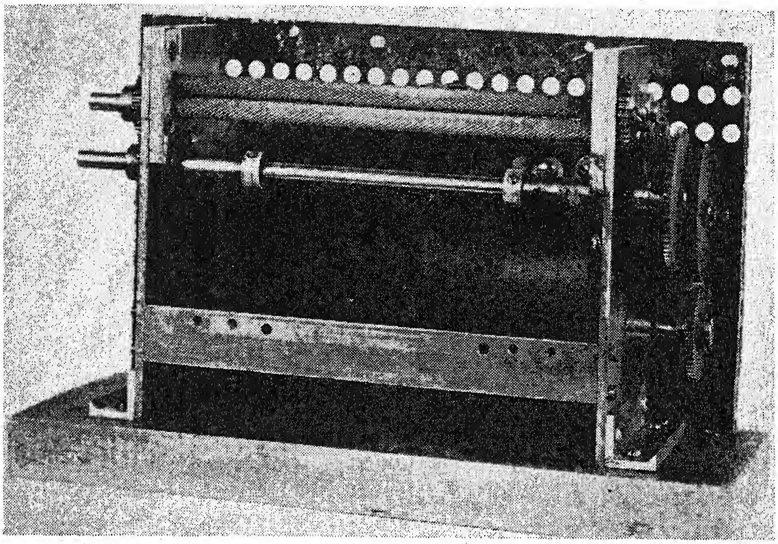


FIG. 2.—Interior view of machine for dehulling oats.

When feeding the kernels into the rollers they should be put in base end first. If put in tip end first the kernels will usually be dehulled but are more likely to be broken or to have part of the kernel pinched off. Very few kernels are broken if they are put in base end first.

Data on the percentage of groats were obtained for five varieties, from 20 samples of each variety dehulled by hand and another 20 samples dehulled by machine. The results obtained are as follows:

Variety No.	Percentage of groats determined from Hand dehulling	Machine dehulling
1	64.2	65.2
2	73.3	73.4
3	66.4	67.1
4	72.9	72.8
5	71.7	71.9

It is seen that the percentages obtained by the two methods agree very well, and it is apparent that the machine will give dependable results.

When using the machine for dehulling to determine the percentage of groats, it is possible that an occasional kernel will be broken. Therefore, studies were made as to a satisfactory method to use in

correcting for this. Twenty samples of 100 kernels each from three varieties were dehulled by the machine. When a kernel or kernels were broken, additional kernels were added (1) by selecting other kernels that weighed the same as the average of the 100 kernels of this particular sample, and (2) by adding the required number of kernels taken at random from the variety. The results of these comparisons are as follows:

	Percentage of groats when kernels are added	
Variety No.	By average weight	At random
1	67.1	67.3
2	73.4	73.6
3	65.2	65.2

There is no important difference in the percentages as determined by these two methods. It may be concluded that accurate results on the percentage of groats will be obtained with the machine by substituting kernels taken at random for any that may be broken in the dehulling process.

One of the advantages of dehulling by machine is that the work can be done by women. With the shortage of men for work of this sort this is important, since dehulling by hand is not an easy process. With a little practice it is possible to feed with both hands and the work of dehulling will proceed rapidly. Tests for germination show that seeds dehulled by the machine germinate just as well as seeds dehulled by hand.—H. H. LOVE AND W. T. CRAIG, *Department of Plant Breeding, Cornell University, Ithaca, N. Y.*

WHAT KINDS OF BULLETINS DO FARMERS READ?[1]

BULLETINS to be read by farmers should be a definite part of the educational program. As such, there might be a definite build-up and timing of bulletins so that the publication would be expected and looked for and "fed" into the educational program at the proper time. Farmers do not always know that a particular bulletin is useful without a "build-up".

The content of a bulletin should fill a definite need to be widely used. A real definite need will get a relatively poorly written work read and used. An example is some of the income tax information.

But by and large, well written, well-illustrated bulletins are read by farmers. Words and terms should be understandable by farmers. Some research in the educational levels of farmer readers would pay dividends in writing bulletins that would be read.

Illustrations and good drawings add enormously to reader interests. Our bulletin, "The Use of Rope on the Farm", is a 48-page bulletin called for in quantities. It was written and illustrated by Virgil Overholt, an agricultural engineer. This bulletin could be understood even though the printed section was in another language—the illus-

[1]Summary of a paper read before Extension Agronomists at the annual meeting of the American Society of Agronomy in Cincinnati, Ohio, November 10, 1943.

trations are so clear. Not all bulletin material can be handled that way.

Out most popular bulletins, "Garment Construction," "Garden Insects and Diseases," "Garden for Victory," "The Use of Rope on the Farm", and some others, are all of fair length, written with full explanations, and well illustrated. The shorter briefs of these bulletins, prepared to save reading time, etc., have not gone as well as the longer bulletins. The bulletins that fill a definite need and are well timed are read by farmers if they are well written and well illustrated.

A good "ghost" writer might get some improvements into bulletins.

A better knowledge of the educational level of the prospective reader, more attention to reader interest, better build-up and timing of bulletins, planning the use of bulletins in the educational program along with meetings, letters, and radio, could make bulletins more useful educational material.—FLOYD DE LASHMUTT, *Department of Rural Economics, Ohio State University, Columbus, Ohio.*

THE SHATTERED DREAM OF A CORN BREEDER[1]

(The following experience is entirely fictitious. Any resemblance between it and that of a breeding program in which selection for combining power antecedes selection for general worthwhileness is purely coincidental.)

Selfed a hundred corn plants,
Put each in a cross;
Selfing without testing,
Means a heavy loss.

Looked around the country,
Found a fertile field,
Used a ten-ten lattice
To find out how they'd yield.

Analyzed the variance,
Wanted just the best;
Planted only thirty,
Threw away the rest.

Thirty, good in hybrids,
That would be a plenty;
Heavy rains, and lodging;
Then there were twenty.

Still had twenty inbreds
Looking mighty keen;
Hot, humid weather;
Smut left thirteen.

[1]Joint contribution from the Bureau of Plant Industry, Soils, and Agricultural Engineering of the Research Administration, U. S. Dept. of Agriculture, and the Tenn. Agr. Exp. Station, Knoxville, Tenn. Read before a meeting of the Crops Section, American Society of Agronomy, Cincinnati, Ohio, November 12, 1943.

Lucky thirteen inbreds,
Glad to be alive;
Wilt, blight, and aphids;
Then there were five.

So passed the summer,
Full of sweat and tears;
Came then the harvest—
Four had rotted ears.

One sturdy inbred,
All, all alone;
It has no sex appeal,
Can't find a home.

FREDERICK D. RICHEY, *Knoxville, Tenn.*

AGRONOMIC AFFAIRS

A. A. A. S. TO MEET IN SEPTEMBER

THE Executive Committee of the American Association for the Advancement of Science has voted to hold the annual meeting of the Association for 1944 in Cleveland, Ohio, during the week of September 11 to 16. It was also voted that in all programs of the September meeting emphasis be placed on the indispensability of science for the future of civilization, both in war and in peace.

The Association has extended a cordial invitation to all affiliated and associated societies to participate in the Cleveland meeting. Since the Association will make all local arrangements and will print the general program, societies intending to meet in Cleveland with the Association are urged to inform the office of the Permanent Secretary, Smithsonian Institution Building, Washington 25, D. C., as promptly as possible.

JOURNAL

OF THE

American Society of Agronomy

VOL. 36 APRIL, 1944 NO. 4

EFFECT OF LIGHT INTENSITY ON ASCORBIC ACID CONTENT OF TURNIP GREENS[1]

K. C. HAMNER AND R. Q. PARKS[2]

SEVERAL investigators (2, 3, 7)[3] working with turnip greens have found differences in ascorbic acid content of from 67 to 422 mg per 100 grams of fresh weight. In recent work at this laboratory with a single variety of turnips, variations similar to those above have been noted in turnips growing under a variety of conditions. In a recent review (5) of the factors causing variation in the ascorbic acid content of plants, a number of citations indicated the importance of light intensity. In an attempt to account for the wide variations in ascorbic acid content which occur in turnip greens, several experiments have been conducted in the field and under controlled conditions designed to study in detail the effects of environmental conditions on ascorbic acid content. Although a detailed report of all of this work is in the course of preparation, the results which have been obtained with respect to the effects of light demonstrated such a striking relationship between light intensity and ascorbic acid content, and the magnitude of the fluctuations in ascorbic acid was so great that it seemed worthwhile to make a brief preliminary report.

METHODS

In all of these experiments, the Shogoin variety of turnips was grown in sand cultures and watered frequently with a nutrient solution found to be satisfactory for good growth. The plants were grown in a chamber under artificial illumination for 16 hours each day. Fluorescent type lamps, half of which were the "daylight" tubes and half of which were the "white" tubes, were used as a source of the illumination and gave an intensity of about 800-foot candles at the leaf surface as measured by a Weston foot-candle meter. The temperature of the room was maintained close to 70° F at all times.

In the first experiment the plants grew rapidly and at the time they were approximately 6 weeks old, the largest leaves were approximately 6 to 8 inches long and about 2 inches wide. At this time, 27 plants were selected for uniformity

---

[1]Contribution from the U. S. Plant, Soil, and Nutrition Laboratory, Agricultural Research Administration, Ithaca, N. Y. Received for publication September 7, 1943.

[2]Agents, U. S. Dept. of Agriculture.

[3]Figures in parenthesis refer to "Literature Cited", p. 273.

of size and divided into nine groups of three plants each. One of these groups remained under the fluorescent tubes to serve as a control, and the other groups were placed at varying distances from four 1,500-Watt, tungsten filament lamps, so that the following intensities of illumination were received by the various respective groups: 200, 600, 800, 1,000, 2,000, 3,000, 4,000, and 5,000 foot candles as measured by a Weston foot-candle meter. The irradiation from the Mazda lamps passed through 6 inches of water before striking the plants, so as to remove most of the infra-red from the light. After exposure at these various intensities for 1 week, all plants were harvested.

The midribs of the leaves from the plants of any particular group were removed and the remainder of the leaves cut into squares about 2 cm on a side. During this cutting, care was exercised so as to injure the leaf tissue as little as possible. Four or more replicate samples were taken from the leaf material of each group and ascorbic acid determinations made on them by the dye-titration method. In addition, on one of the replicates from each group, ascorbic acid measurements were made both before and after H_2S treatment, according to the method of Bessey (1). This latter method measured the amount of dehydroascorbic acid present and also constituted a check on the accuracy of the titration method. Dehydroascorbic acid found by this method in no case accounted for over 3% of the total ascorbic acid activity. No significant differences in ascorbic acid content between the two methods occurred.

RESULTS

The results of the experiment are recorded in Table 1. It is evident that the ascorbic acid content of the turnips is closely related to the light intensity to which the plants were exposed 1 week previous to harvest. In another experiment, plants of a comparable age were transferred from under the fluorescent tubes (at 800 foot candles) to illumination of 5,000 foot candles for 5 days. The ascorbic acid content rose from 88.8 to 242.4 mg. per 100 grams fresh weight as a result of the change in intensity.

TABLE 1.—*Ascorbic acid content of "turnip greens" exposed for 1 week to various light intensities.*

Light intensity, ft. candles	No. of samples	Ascorbic acid, mg per 100 gms fresh weight, Mean±S E
200	6	28.2±1.22
600	4	79.0±3,63
800	7	84.2±4.37
1,000	4	112.6±6.67
2,000	4	133.6±3.65
3,000	4	183.8±5.85
4,000	4	193.8±2.44
5,000	4	235.5±12.41
800*	4	83.9±2.05

*These plants were controls which were exposed to illumination of 800 ft. candles from fluorescent tubes throughout their lives. All other plants were exposed at the various intensities for 1 week to illumination from tungsten filament lamps.

In order to determine whether or not similar changes occur in older plants and how rapid is the response, the following experiment was carried out. Three large turnip plants which had been grown in

the greenhouse for about 4 months (Fig. 1) were removed to the control room on April 21. Three representative leaves were taken from each plant and ascorbic acid determinations made in quadruplicate in a manner similar to that described above. At the time the plants were transferred from the greenhouse, plant B had 151.9 mg of ascorbic acid per 100 grams of fresh weight, plant C 172.7 mg, and plant A 154.7 mg. Plant B was then placed under the Mazda lights at an intensity of approximately 6,000 foot candles, while plants A and C were placed under the fluorescent lights at an intensity of

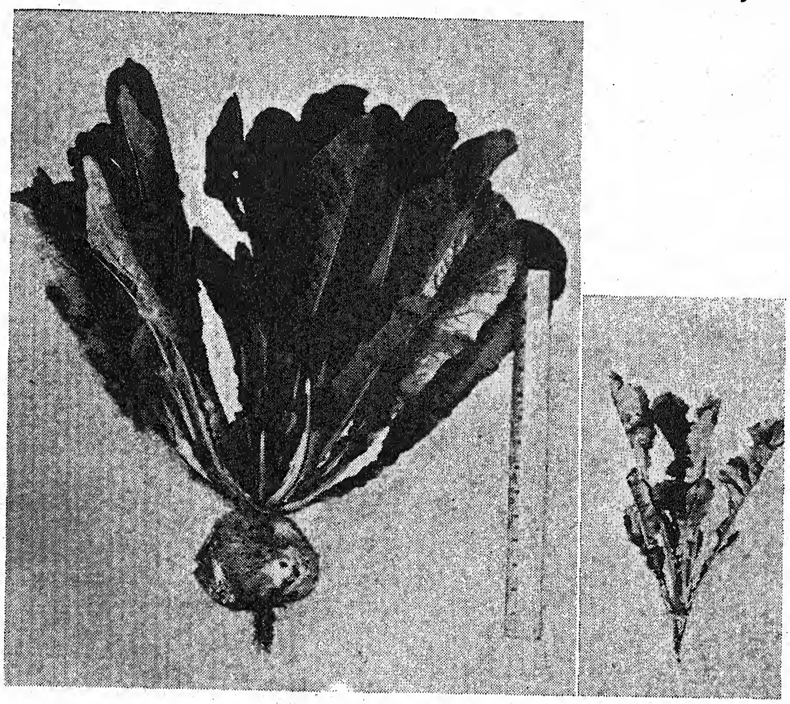


FIG. 1.—Comparison of sizes of young and old turnip plants used in light intensity experiments.

approximately 800 foot candles. Ascorbic acid determinations were made on each of the plants every day or every other day. After 7 days at which time the ascorbic acid content of plant B had reached a value of approximately 200 mg per 100 grams, and plants C and A had decreased in value to 124 and 100 mg, respectively, plant A was transferred to a position under the Mazda lamps and plant B to a position under the fluorescent lamps. During subsequent days, the ascorbic acid content of plant A rapidly increased to 200 mg and that of plant B decreased relatively more slowly. Little change in ascorbic acid values of plant C occurred after the seventh day. These relationships are illustrated in Fig. 2. The results illustrate the close interrelationship between light intensity and ascorbic acid content of turnip leaves.

DISCUSSION

It seems evident that variations in light intensity may cause a rapid and relatively great variation in the ascorbic acid content of turnip greens. Reid (6), working with cowpea seedlings, found that high daylight intensities and medium to long days favored the accumulation of ascorbic acid while low light intensities and short days had a depressing effect. Kohman and Porter (4), working with young tomato plants noted a rapid decrease in ascorbic content when the plants were transferred from conditions of natural sunlight in the open to the diffuse daylight of the laboratory with a subsequent increase upon return to the open.

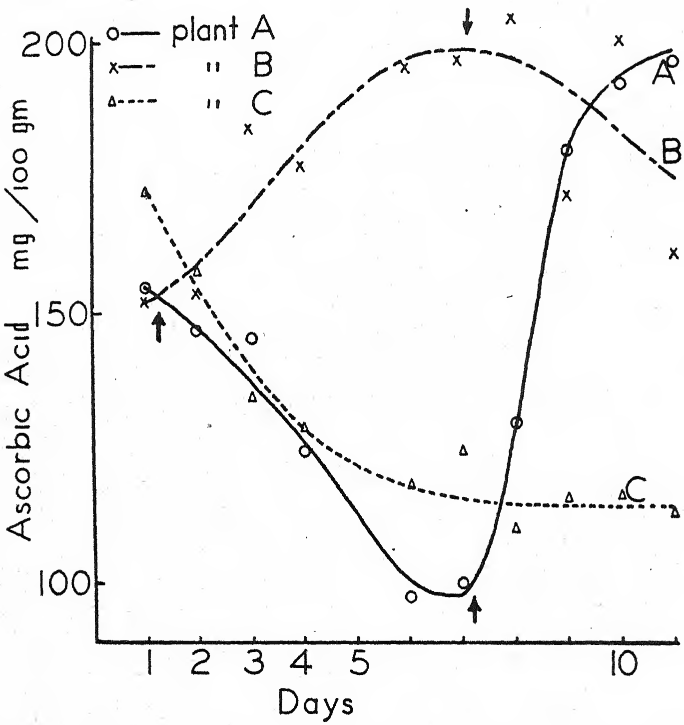


FIG. 2.—Ascorbic acid values of tops of three large turnip plants grown in the greenhouse and shifted to the control room for experimentation. Plant B from high to low light intensity, plant A from low to high light intensity, and plant C continuously at low light intensity. Shifts are designated by arrows.

Our results with turnips under carefully controlled conditions illustrate a quantitative relationship between light intensity and ascorbic acid level. This relationship is almost identical in both young and old plants.

Other results recently obtained have indicated that most of the naturally occurring variations in ascorbic acid content of turnip

greens cannot be accounted for on the basis of variations in temperature, mineral supply, or relative humidity.

We are inclined to conclude, therefore, that light intensities just prior to harvest play the dominant role in determining ascorbic acid level. It would seem evident, apart from all other considerations, that, if turnip greens are to be harvested for their maximum ascorbic acid content, harvesting should occur after a period of bright sunny weather.

LITERATURE CITED

1. Bessey, O. A. Method for the determination of small quantities of ascorbic acid and dehydroascorbic acid in turbid and colored solutions in the presence of other reducing substances. Jour. Biol. Chem., 126:771–784. 1938.
2. Floyd, W. W., and Fraps, G. S. Changes in vitamin C during the boiling of turnip greens. Food Res., 5:33–41. 1940.
3. Keller, M. L., and Minot, A. S. "Pot liquor": a neglected source of vitamin C for the feeding of infants. Southern Med. Jour., 34:163–64. 1941.
4. Kohman, E. F., and Porter, D. R. Solar rays and vitamin C. Science, 92:561. 1940.
5. Maynard, L. A., and Beeson, K. C. Some causes of variation in the vitamin content of plants grown for food. Nutrition Abs. & Reviews, 13:155–164. 1943.
6. Reid, M. E. Effect of variations in light intensity, length of photo-period, and availability of nitrogen upon accumulation of ascorbic acid in cowpea plants. Bul. Torrey Bot. Club, 69:204–220. 1942.
7. Tul'chinskaya, K. Z. Antiscorbutic vitamin concentrates from some inedible products. IV. Preparing vitamin C concentrates from sugar-beet leaves. Vitamin Res., U.S.S.R., 3:59–64. 1941.

AGRONOMIC VALUE OF ALKYLATION-ACID SUPERPHOSPHATE AS INDICATED BY GREENHOUSE AND LABORATORY EXPERIMENTS[1]

EILIF V. MILLER AND K. D. JACOB[2]

THE alkylation process for the manufacture of aviation gasoline (5, 6, 7),[3] which involves reacting isobutane with butylene in the presence of a catalyst (usually sulfuric acid) was first introduced in the development stage in 1939. Under the stimulus of war demands, the process was rapidly developed and is now used by a number of plants throughout the country. In the operation of the process, sulfuric acid is introduced into the system at a concentration of 98 to 100% H_2SO_4 and is discharged as spent acid which contains about 88 to 91% H_2SO_4 by weight, is very dark in color, and is contaminated with hydrocarbons. In its characteristics and in the nature of its contaminants, the alkylation spent acid differs from the spent sulfuric acid ("sludge" acid) commonly obtained in the refining of petroleum products by acid-treatment processes (2).

Inasmuch as it appeared likely that a considerable tonnage of alkylation spent acid would be available for use in the manufacture of superphosphate, it was considered desirable to make a study of the agronomic value of superphosphate produced with such acid. Accordingly, an extensive series of laboratory, greenhouse, and field experiments was undertaken, the last principally in cooperation with the Division of Fruit and Vegetable Crops and Diseases and with several state agricultural experiment stations. The results of the laboratory and greenhouse studies are reported in the present paper.[4]

EXPERIMENTAL MATERIALS AND METHODS

The superphosphates used in these studies were made in the same plant from the same lot of Tennessee brown-rock phosphate under identical conditions of commercial production and curing.[5]

For the manufacture of the alkylation-acid superphosphate, the spent acid, which contained 89.9% H_2SO_4, was diluted to the proper concentration (54° Baumé, 68.13% H_2SO_4) and mixed with an equivalent quantity of clear acid. Analyses of representative samples of the superphosphates, taken at the time they were shipped from the plant (about 4 weeks after they were made), showed total

---

[1]Contribution from Division of Soil and Fertilizer Investigations, Bureau of Plant Industry, Soils, and Agricultural Engineering, U. S. Dept. of Agriculture, Beltsville, Md. Presented before the Division of Fertilizer Chemistry at the 106th meeting of the American Chemical Society, Pittsburgh, Pa., September 6 to 10, 1943. Received for publication September 23, 1943.

[2]Formerly Junior Chemist, now Associate Soil Technologist, Office of Foreign Agricultural Relations; and Senior Chemist, respectively.

[3]Figures in parenthesis refer to "Literature Cited", p. 280.

[4]The results of field tests on potatoes in Maine have been reported by Brown, *et al.* (1), while those of experiments on other crops in Connecticut, New Jersey, Maryland, Iowa, and Michigan are reported in the following paper (4).

[5]The superphosphates were kindly made in February, 1942, by The American Agricultural Chemical Company, East St. Louis, Ill., especially for this investigation.

P_2O_5 19.60%, 19.90%; water-soluble P_2O_5 15.30%, 14.73%; and available P_2O_5 17.74%, 17.18% in the clear-acid and the alkylation-acid superphosphates, respectively.

The greenhouse experiments were made in 8-inch, bottom-pierced, clay pots with German millet, Korean lespedeza, and Detroit Dark Red table beets grown in Evesboro loamy sand (11 pounds per pot) from the Beltsville Research Center, Beltsville, Md., and in Chester loam (10 pounds per pot) from the Esther Scott farm near Sandy Spring, Md. The soils were obtained from the surface of areas that had not been in cultivation for many years. They were passed through a screen of ⅛-inch mesh. The initial glass-electrode pH values of the air-dry field soils, determined on 1:1 soil-water suspensions, were 5.92 and 5.19 for the Evesboro and Chester soils, respectively. The pots and their supporting saucers were coated with water-proof varnish. The experiments were run in quadruplicate.

The soils were fertilized with an 8–0–8 mixture, at the rate of 1,000 pounds per acre, which was composed of sodium nitrate 245, ammonium sulfate 385, dried blood 298, potassium chloride 274, calcined kieserite 100, dolomite 400, powdered pyrex glass (to supply boron) 25, gypsum 75, and sand 198 parts. As the purpose of these experiments was primarily to determine whether alkylation-acid superphosphate contains any substances that are harmful to plants, the rate of application of the superphosphates was varied from 250 to 2,000 pounds of total P_2O_5 per acre (based on a weight of 2,000,000 pounds of soil per acre) in order to simulate the concentrations that may prevail in the root zone under field conditions. The basal fertilizer and the phosphates were thoroughly mixed with the upper half of the soil in each pot, although the rates of application were based on the total weight of soil in the pot. Supplemental applications of nitrogen (80 pounds per acre, as a solution of equivalent quantities of sodium nitrate and ammonium sulfate) and magnesium (40 pounds per acre, as a solution of magnesium sulfate) were made to the millet plants at 5 weeks of age.

Seeding was accomplished with the aid of a template to provide uniform spacing. Data on the rates and dates of seeding, number of plants grown, and dates of harvesting are given in Table 1. The beet pots were covered with cheesecloth during germination of the seeds and were shaded by a single thickness of the cloth for a week thereafter to prevent scalding of the young plants. Some transplanting was necessary to obtain three uniformly spaced beet plants. Where it was possible, the transplants were taken from the replicate pots; otherwise, they were taken from pots that had received only the basal fertilizer. The soils were maintained at the desired moisture contents by additions of tap water. At intervals during the later stages of growth of the millet and lespedeza the pots were watered from the saucer in order to favor the movement of nutrients upward in the soil. The beets were watered only from the saucer during the last 6 weeks of growth.

TABLE 1.—*Data relating to the pot experiments.*

Crop	No. of seeds planted	No. of plants grown	Date of seeding	Date of harvesting
Lespedeza..........	38	13	June 22	Sept. 9
Millet..............	15	7	June 22	Aug. 17
Beet...............	6	3	July 17	Sept. 25

The harvested millet and lespedeza plants (total aerial portions) were dried in a forced-draft oven at 150°F for 48 hours and were then exposed to the laboratory

atmosphere for 1 to 2 weeks before they were weighed. The yields of beets (roots only) were determined on the green-weight basis.

EFFECT OF SUPERPHOSPHATES ON PLANT GROWTH

As shown in Fig. 1, the clear-acid and the alkylation-acid superphosphates had practically identical effects on the dry-weight yields of the total aerial portions of millet and lespedeza at all rates of application (250 to 2,000 pounds of total P_2O_5 per acre). Also, at the same rate of application, there were no considerable differences between the effects of the superphosphates on the dry-weight yields of millet heads nor on the germination of the seeds and the survival of the plants of any of the crops. At the highest rate of application (2,000 pounds of P_2O_5 per acre) both superphosphates induced a distinct striping of the blades of millet plants on the Evesboro soil at 2.5 weeks of age. This effect, which had disappeared by the time the

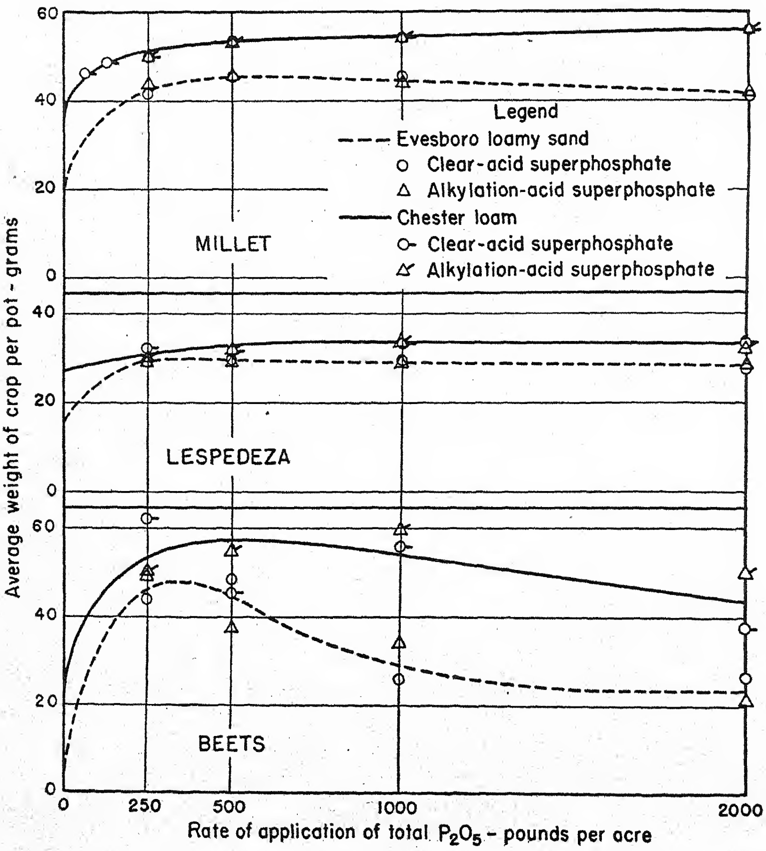


FIG. 1.—Effects of superphosphates on growth of German millet, Korean lespedeza, and Detroit Dark Red table beets. Dry weights of total aerial portions of millet and lespedeza; fresh weights of beet roots.

plants were 5 weeks old, may have been due, at least in part, to a deficiency of nitrate nitrogen in the culture, as indicated by the data in Fig. 2.

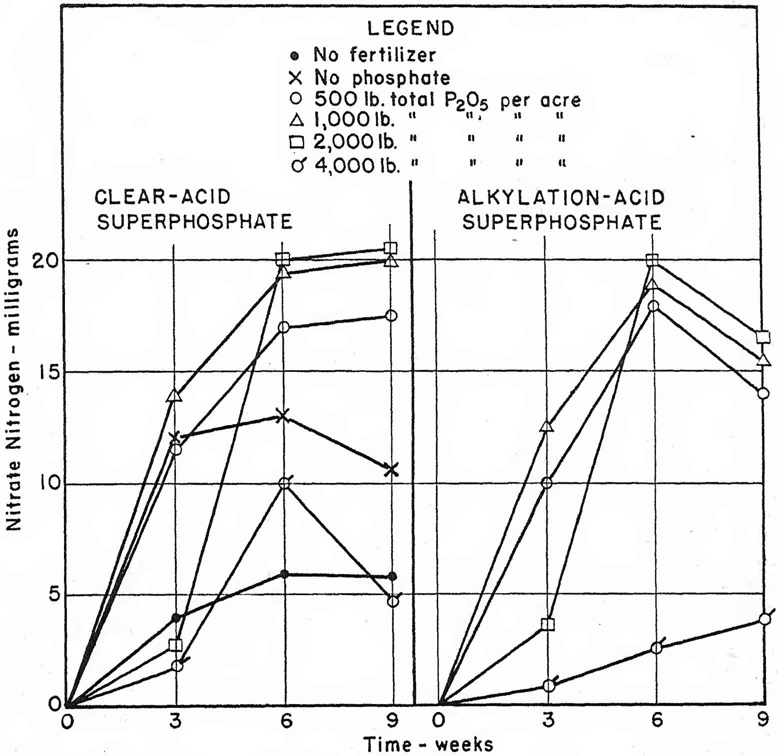


FIG. 2.—Effect of superphosphates on rate of nitrification of ammonium sulfate in 100-gram cultures of Evesboro loamy sand.

With lespedeza on the Evesboro soil, both superphosphates at the application rates of 1,000 and 2,000 pounds of P_2O_5 per acre induced marginal firing of the leaves and stunting of the whole plant at 4 weeks of age. This condition largely disappeared during the later stages of growth. Poor stands of beets were obtained with both superphosphates at the two highest rates of application, especially on the Evesboro soil. Both these rates definitely depressed the yields on the Evesboro soil, and the 2,000-pound application appeared to have an adverse effect with the Chester soil. Although the yield differences between the two superphosphates at a given rate of application were much larger with beets than with millet and lespedeza, the results were such that no adverse effects on beets can be ascribed specifically to the alkylation-acid superphosphate in comparison with the clear-acid superphosphate.

EFFECT OF SUPERPHOSPHATES ON SOIL pH VALUES

The pH values of the Evesboro soil under millet were determined, after 3 weeks and 8 weeks of plant growth, by means of the glass electrode on 1:1 suspensions of soil and distilled water. For a given application of phosphorus, the results (Table 2) show, in general, slightly higher pH values with the alkylation-acid superphosphate than with the clear-acid superphosphate at 3 weeks but not at 8 weeks. In general agreement with the results obtained by Sewell, Latshaw, and Tague (8) with additions of superphosphate (500 to 20,000 pounds per acre) to fallow Bates silt loam soil (original pH value of 5.02) under greenhouse conditions, there was no definite trend in pH values with increasing applications of phosphorus. The lower pH values for the soil of all the fertilized pots at 8 weeks were doubtless due principally to the supplemental application of nitrogen that these pots received at 5 weeks.

TABLE 2.—*Effect of superphosphates on pH value of Evesboro loamy sand under German millet.*

Type of superphosphate	Application of P_2O_5, lbs. per acre	pH value* of 1:1 soil-water suspension after	
		3 weeks†	8 weeks‡
None§	0	5.68	5.81
None**	0	5.52	4.74
Clear acid	250	5.45	4.47
Alkylation acid	250	5.59	4.56
Clear acid	500	5.28	5.03
Alkylation acid	500	5.37	4.72
Clear acid	1,000	5.37	4.90
Alkylation acid	1,000	5.56	4.88
Clear acid	2,000	5.49	4.56
Alkylation acid	2,000	5.23	4.94

*The initial pH value of the air-dry field soil was 5.92.
†Determined on moist topsoil from the center of the circle of plants in the pot.
‡Determined on a composite sample of air-dry soil taken from the upper half of the replicate pots after the plants were harvested.
§No fertilizer.
**No phosphorus.

EFFECT OF SUPERPHOSPHATES ON NITRIFICATION OF AMMONIUM SULFATE

Brown, Jacob, and Reid (2) reported that equal quantities of P_2O_5 (1,000 pounds per acre) from superphosphates made, respectively, with clear sulfuric acid and with "sludge" sulfuric acid from the refining of petroleum products had similar effects on the nitrification of ammonium sulfate in a sandy loam soil. In order to determine the effects of alkylation-acid superphosphate on nitrifying organisms, experiments were run in the usual manner with 100-gram portions of the Evesboro soil to which were added 1 gram of precipitated calcium carbonate, 100 mg of C.P. ammonium sulfate, and the superphosphates at respective rates of 500, 1,000, 2,000, and 4,000 pounds of total P_2O_5 per acre. The cultures were maintained in the moist condition and were incubated at 28 to 31.5°C. Nitrate nitrogen was

determined in the centrifuged extracts of duplicate cultures at 3, 6, and 9 weeks, respectively, by the phenol disulfonic acid method.

In general, equal quantities of the two superphosphates had similar effects on the nitrification of ammonium sulfate (Figs. 2 and 3). In the first 3 weeks, nitrification was slightly improved by the superphosphates at the 500- and 1,000-pound rates of application but was markedly depressed by the 2,000-pound applications. By the end of 6 weeks, however, nitrification had been stimulated considerably by the superphosphates at all three rates of application. On the other hand, nitrification was greatly inhibited by the 4,000-pound applications throughout the 9 weeks of the experiment.

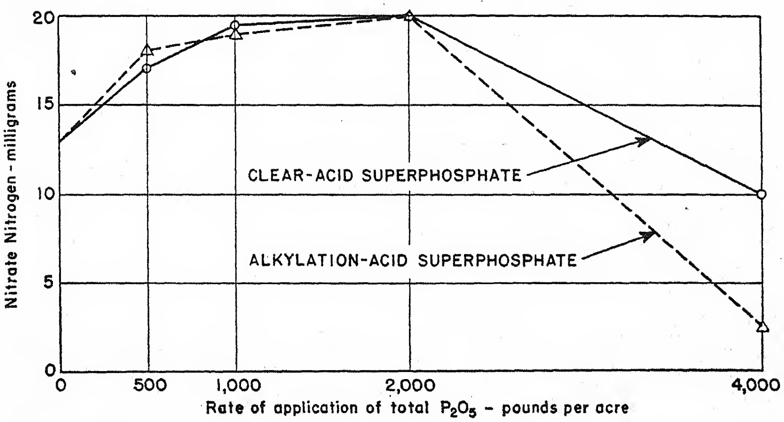


FIG. 3.—Effect of rate of application of superphosphates on nitrification of ammonium sulfate in 100-gram cultures of Evesboro loamy sand at 6 weeks.

Fraps and Sterges (3) found that nitrification of ammonium sulfate in certain Texas soils was stimulated by additions of 20% superphosphate at the rate of 2,050 pounds of total P_2O_5 per acre.

SUMMARY

Superphosphates made in the one case with clear sulfuric acid and in the other with spent sulfuric acid from the manufacture of high-octane gasoline by the alkylation process, had practically identical effects on the growth of German millet, Korean lespedeza, and Detroit Dark Red table beets in Evesboro loamy sand and Chester loam soils under greenhouse conditions, even when they were applied at rates as high as 2,000 pounds of total P_2O_5 per acre.

At the same rates of application, the superphosphates had similar effects on the pH values of the Evesboro soil under millet in the greenhouse experiments, and on the nitrification of ammonium sulfate in laboratory experiments with the same soil.

LITERATURE CITED

1. BROWN, B. E., CAMPBELL, J. C., HAWKINS, A., HOUGHLAND, G. V. C., and JACOB, K. D. An evaluation of sludge-acid and alkylation-acid superphosphates as sources of phosphorus in potato fertilizers: Field studies in Maine, New Jersey, Pennsylvania, and Virginia. Amer. Potato Jour., 20: 89–95. 1943.
2. ————, JACOB, K. D., and REID, F. R. Plant culture and nitrification studies with sludge-acid superphosphates. Amer. Fert., 96(7): 5–6, 24, 28. 1942.
3. FRAPS, G. S., and STERGES, A. J. Effect of phosphates on nitrifying capacity of soils. Soil Sci., 47:115–121. 1939.
4. JACOB, K. D., and ARMIGER, W. H. Field experiments with alkylation-acid superphosphate. Jour. Amer. Soc. Agron., 36:281–286. 1944.
5. KENNY, L. M. Problems in alkylation plant operation. Refiner and Natural Gasoline Manufacturer, 21: 193–195. 1942.
6. MCALLISTER, S. H. High-antiknock aviation fuels from light hydrocarbons. Oil and Gas Jour., 39(29):42, 45, 47, 48. 1940.
7. MURPHY, G. B. Alkylation-oil industry's contribution to war requirements of aviation fuel. Nat. Petrol. News, 34(1):R-4, R-6, R-8. 1942.
8. SEWELL, M. C., LATSHAW, W. L., and TAGUE, E. L. The effect of acid phosphate on soil reaction and growth of alfalfa. First Int. Cong. Soil Sci., Proc. and Papers, Comn. 2, 2:439–455. 1927.

FIELD EXPERIMENTS WITH ALKYLATION-ACID SUPERPHOSPHATE[1]

K. D. JACOB AND W. H. ARMIGER[2]

IN the preceding paper[3] it was shown that superphosphates produced, respectively, with clear sulfuric acid and with spent sulfuric acid from the manufacture of high-octane gasoline by the alkylation process had practically identical effects on the growth of millet, lespedeza, and table beets under greenhouse conditions. The present paper gives the results of field experiments with these superphosphates on a wide variety of crops, principally in cooperation with the Division of Fruit and Vegetable Crops and Diseases, U. S. Dept. of Agriculture, and with the Connecticut, Iowa, Maine, Michigan, and New Jersey agricultural experiment stations. Also, experiments on barley were made by the Ohio Agricultural Experiment Station in 1942 and 1943, but the crop failed in both years. As the state of combination of the phosphorus is the same in both types of superphosphate, the purpose of the investigation was to determine whether the material produced with the spent acid contains impurities that may be harmful to plants. The characteristics and chemical compositions of the superphosphates are given in the preceding paper.

EXPERIMENTS IN CONNECTICUT

In Connecticut, experiments were made by the New Haven Station on alfalfa and sweet corn (variety Inbred C 31) and by the Storrs Station on potatoes (variety Green Mountain) and Sudan grass.

The alfalfa and sweet corn experiments were on 1/30th-acre plots of level, Cheshire fine sandy loam in the Maurice Rogers farm, Mt. Carmel, Hamden. The alfalfa land was in grass from 1920 to 1940 and had received little or no fertilizer. It was seeded to alfalfa in the spring of 1940, and in the spring of 1941 was treated with 3 tons of limestone and approximately 100 to 125 pounds of superphosphate per acre. The clear-acid and the spent-acid superphosphates, in mixtures with potassium chloride, were broadcast by hand on the alfalfa on April 22, 1942. The first cutting of alfalfa in 1942, which was delayed be-

[1]Contribution from the Division of Soil and Fertilizer Investigations, Bureau of Plant Industry, Soils, and Agricultural Engineering, U. S. Dept. of Agriculture, Beltsville, Md. Received for publication September 23, 1943.

[2]Senior Chemist and Junior Agronomist, respectively. Grateful acknowledgment is made of the cooperation of Oswald Schreiner, Division of Soil and Fertilizer Investigations; B. E. Brown, Division of Fruit and Vegetable Crops and Diseases; H. A. Lunt, Connecticut (State) Agricultural Experiment Station; B. A. Brown, Connecticut (Storrs) Agricultural Experiment Station; H. R. Meldrum and W. H. Pierre, Iowa Agricultural Experiment Station; Arthur Hawkins, formerly with the Maine Agricultural Experiment Station, now with the Division of Soil and Fertilizer Investigations; J. F. Davis and C. E. Millar, Michigan Agricultural Experiment Station; F. E. Bear, New Jersey Agricultural Experiment Station; and E. E. Barnes and R. E. Yoder, Ohio Agricultural Experiment Station.

[3]MILLER, EILIF V., and JACOB, K. D. Agronomic value of alkylation-acid superphosphate as indicated by greenhouse and laboratory experiments. Jour. Amer. Soc. Agron., 36:274–280. 1944.

yond the normal cutting stage and which contained an unusually large amount of timothy, was made on June 27 and the second cutting on September 4.

The sweet corn experiments were on land which previously had been in grass. It was treated with lime and complete fertilizer and was planted to corn in 1940 and, without further treatment, again in 1941. The superphosphates, together with a mixture of ammonium sulfate, sodium nitrate, urea, and potassium chloride, were broadcast by hand on May 18, 1942. The corn was planted on May 29 and the crop was harvested on October 16. The results are presented in Table 1.

TABLE 1.—*Effects of superphosphates on yields of alfalfa and sweet corn, Connecticut (State) Agricultural Experiment Station, New Haven.*

Treatment*	Alfalfa, lbs.†			Sweet corn, lbs.‡
	First cutting	Second cutting	Total	
No fertilizer	——	938	——	23.3
P_C	4,057	1,491	5,548	30.5
P_S	4,109	1,424	5,533	31.3
$2P_C$	4,111	1,426	5,537	27.6
$2P_S$	4,051	1,616	5,667	29.7

*For alfalfa: P and 2P = 200 and 400 pounds of superphosphate per acre, respectively; all fertilized plots received KCl at the rate of 150 pounds per acre. For sweet corn: P and 2P = 250 and 500 pounds of superphosphate per acre, respectively; all fertilized plots received N and K_2O at rates of 32 and 54 pounds per acre, respectively.

†Average yields of dry matter per acre; three replications.

‡Average yields of husked seed corn on cob per 100 feet of row; three replications.

At the Storrs Station, potatoes were grown on Merrimac fine sandy loam (pH 5.0, low in easily soluble phosphorus, and very low in soluble magnesium, calcium, and potassium) in field L7 on the Vegetable and Agronomy Experimental Farm, North Coventry. The plots, the dimensions of which were 150 feet by 6 feet (two rows), had been used for potato fertilizer placement and time of application tests in 1940 and 1941. The superphosphates, in mixtures with nitrogen, potassium, and magnesium salts, were applied in bands on each side of the seed piece at the time the potatoes were planted, May 23, 1942. The crop was harvested in early October.

The experiments with Sudan grass were on plots (94 feet by 12 feet) of Charlton fine sandy loam in field X (south), Agronomy field, Storrs. These plots had been in Kentucky bluegrass and white clover from 1939 to 1941, inclusive, without removal of the mown clippings, and had received 40% superphosphate at the rate of 200 pounds per acre in April, 1939. The superphosphates, in mixtures with nitrogen and potassium carriers, were applied broadcast and disked in shortly before the Sudan grass was sown by hand on cultipacked soil and covered with a drag "bush" on June 17, 1942. The grass was harvested at the seeding stage on August 31.

Statistical analysis of the yields of alfalfa and sweet corn in the experiments by the Connecticut State Station at New Haven showed no significant differences between the results obtained with the two

types of superphosphates (Table 1).[4] At the Storrs Station (Table 2), the average yield of Sudan grass from the plots receiving the clear-acid superphosphate was higher, though probably not significantly so, than that from the plots fertilized with the spent-acid superphosphate. On the other hand, the yields of potatoes were considerably higher with the spent-acid than with the clear-acid superphosphate. It should be mentioned that the planter used in applying the fertilizers to the potato plots delivered 5% more of the mixture containing the spent-acid superphosphate than of the one containing the clear-acid material. As the carriers of nitrogen, phosphorus, and potassium were applied, however, at rates previously found more than ample for maximum yields of potatoes on these plots, it seems unlikely that this small difference in weight of fertilizer was responsible for the larger yields with the spent-acid superphosphate.

TABLE 2.—*Effects of superphosphates on yields of potatoes and Sudan grass, Connecticut (Storrs) Agricultural Experiment Station.*

Treatment*	Potatoes, bu.†		Sudan grass	
	U. S. grade No. 1	Total	Average height when cut, in.	Average yield, lbs.‡
No P	—	—	68	3,118
P_c	264	305	72	3,740
P_s	314	357	71	3,530

*For potatoes: P = 900 pounds of superphosphate per acre; all plots received $(NH_4)_2SO_4$, 60 percent KCl, and epsom salts at respective rates of 500, 270, and 100 pounds per acre. For Sudan grass: P = 300 pounds of superphosphate per acre; all plots received Uramon and 60% KCl at respective rates of 140 and 160 pounds per acre.
†Average yield per acre; two replications.
‡Dry matter per acre; three replications.

EXPERIMENTS IN IOWA

In Iowa, experiments with oats were made on Carrington silt loam at the Rollo Batcheler farm, Central City; on Clarion loam at the College farm, Ames; on Clarion silt loam at the Ed. Syndegard farm, Redfield; and on Edina silt loam at the Dr. Chester farm, Albia. The oats were planted between April 3 and 10, 1942, and the crops were harvested on July 14 to 16. The results (Table 3) show no significant differences between the yields obtained by the use of the two types of superphosphates.

An experiment with alfalfa was made on Weller silt loam at the J. S. Judge farm, Moravia. The field, which had been cropped heavily to cereals, was limed in 1941 at the rate of 3 tons per acre, and oats were grown in that year. The superphosphates, together with potassium chloride, were applied broadcast on April 3, 1942, and thoroughly disked into the soil. The alfalfa was seeded without a nurse crop. The stand was not very uniform and only one cutting was made for hay in 1943. A statistical analysis of the results (Table 3) showed that

[4]In all the tables, the clear-acid and the spent-acid superphosphates are designated, respectively, by the letters c and s as subscripts to the letter P.

TABLE 3.—*Effects of superphosphates on yields of oats and alfalfa, Iowa Agricultural Experiment Station.*

Treatment*	Average yield per acre					
	Oats, bu.					Alfalfa, lbs., Weller silt loam**
	Carrington silt loam†	Clarion loam‡	Clarion silt loam†	Edina silt loam§	Average	
K......	54.7	39.3	30.9	60.2	46.3	1,700
K-P_c...	66.2	41.6	35.6	66.0	52.4	2,348
K-P_s...	63.6	43.5	31.4	63.3	50.5	2,194
2P_c.....	63.1	42.9	30.0	64.5	50.1	—
K-2P_c..	67.2	40.4	36.0	66.2	52.5	2,977
K-2P_s	66.3	42.3	37.6	68.2	53.6	2,609

*K = 60 pounds of K_2O per acre as KCl (60% K_2O). P and 2P = 30 and 60 pounds of available P_2O_5 per acre, respectively.
†Four replications.
‡Six replications.
§Two replications.
**Four replications, yield on dry-weight basis. A difference of 481 pounds between the yields obtained with the two superphosphates is required for significance at the 0.05 level.

the yields obtained with the alkylation-acid superphosphate were not significantly different from those obtained with the clear-acid superphosphate.

EXPERIMENTS IN MAINE

The experiments in Maine, which have already been described by Brown, *et al.*[5] and which are summarized here for the sake of completeness, were run on Caribou loam at the Amos H. Fletcher farm, Caribou, and at the Aroostook Farm, Maine Agricultural Experiment Station, Presque Isle. At Caribou, Green Mountain potatoes were planted on June 1, 1942, and harvested on October 1. At Presque Isle Sebago potatoes were planted on June 12 and harvested on October 11. The pH values of the soils were 5.2 to 5.4 and 5.0 to 5.2, respectively. The superphosphates, in mixtures with other fertilizer materials, were applied by machine in conjunction with the planting of the seed pieces. The placement was as individual bands 2 inches on each side and slightly below the level of the lower plane of the seed pieces. Statistical analysis of the results (Table 4) showed no significant differences between the yields obtained with the spent-acid and the clear-acid superphosphates.

EXPERIMENTS IN MARYLAND

The superphosphates were compared as sources of phosphorus in complete fertilizers for oat hay and wheat on 1/40-acre plots of a very poor Altavista silt loam on the Field Crops Farm, Bureau of Plant Industry, Soils, and Agricultural Engineering, Beltsville, Md. The

[5]BROWN, B. E., CAMPBELL, J. C., HAWKINS, A., HOUGHLAND, G. V. C., and JACOB, K. D. An evaluation of sludge-acid and alkylation-acid superphosphates as sources of phosphorus in potato fertilizers: field studies in Maine, New Jersey, Pennsylvania, and Virginia. Amer. Potato Jour., 20:89–95. 1943.

TABLE 4.—*Effects of superphosphates on yields of potatoes, Maine Agricultural Experiment Station.*

Treatment*	Average yield per acre, bu.	
	Caribou†	Aroostook Farm‡
No P	399	133
P_C	432	—
P_S	464	—
$2P_C$	443	245
$2P_S$	431	224

*No P = 2,000 pounds of 4–0–10 mixed fertilizer per acre; P and 2P = 2,000 pounds of 4–4–10 and 4–8–10 mixed fertilizers per acre, respectively.
†Eight replications.
‡Six replications.

soil received a broadcast application of ground limestone at the rate of 1,750 pounds per acre in the spring of 1942. The fertilizer was applied broadcast and harrowed into the soil on May 15. The plots were seeded to white spring oats on May 18, and on May 19 a mixture of red clover, alfalfa, and timothy was sown. The oats were harvested for hay on July 9, and later the sparse stand of alfalfa, clover, and timothy was turned under. On November 18, 1942, a second application of the fertilizers, in the same kind, manner, and quantity as with the respective plots of oats was made, and wheat (variety Leapland) and timothy were sown. A mixture of alfalfa and red clover was sown broadcast on the surface of the plots on March 25, 1943. The wheat was harvested on June 25. As shown in Table 5, there were no consistent differences between the effects of the two superphosphates on the yields of oat hay and of wheat grain and straw.

TABLE 5.—*Effects of superphosphates on yields of oat hay and wheat, Bureau of Plant Industry, Soils, and Agricultural Engineering, Beltsville, Md.*

Treatment*	Yield per acre†		
	Oat hay, lbs.‡	Wheat	
		Straw, lbs.‡	Grain, bu.
No fertilizer	250	640	5.3
P_C	630	1,230	12.2
P_S	800	1,230	9.5
$2P_C$	620	1,300	13.3
$2P_S$	660	1,280	13.5
$4P_C$	770	1,400	13.5
$4P_S$	770	1,360	13.1

*P, 2P, and 4P = 400 pounds of 4–4–8, 4–8–8, and 4–16–8 mixed fertilizer per acre, respectively.
†Single plots.
‡Air-dry weight.

EXPERIMENTS IN MICHIGAN

The Michigan experiments were carried out with barley on Miami silt loam at the John Dilman farm, near Cass City, Tuscola County, and with sugar beets on Brookston clay loam at the C. L. Bobit farm

near Breckenridge, Gratiot County. For barley, the superphosphates, without nitrogen and potassium fertilizers, were applied in contact with the seed by means of the grain drill on April 21, 1942, and the crop was harvested on July 28. For sugar beets, the superphosphates, in mixtures with nitrogen and potassium fertilizers were drilled in a band 1 inch to the side and 1.75 inches below the seed. The seeds were planted on April 30, 1942, and the beets were harvested on October 6. The two superphosphates were about equally effective in increasing the yields of both crops (Table 6).

TABLE 6.—*Effects of superphosphates on yields of barley and sugar beets, Michigan Agricultural Experiment Station.*

Treatment*	Average yield per acre†	
	Barley, bu.	Sugar beets, tons
No fertilizer	47.2	3.2
P_C	55.6	13.8
P_S	55.4	12.3

*For barley, the superphosphates were applied, without N and K, at the rate of 300 pounds per acre. For sugar beets, the superphosphates were applied at the rate of 300 pounds of 2–16–8 mixed fertilizer per acre.
†Four replications for barley and five for sugar beets.

EXPERIMENTS IN NEW JERSEY

In New Jersey, the superphosphates, in mixtures with nitrogen and potassium fertilizers, were applied to field corn which was harvested for silage on August 21, 1942. The soil was a Sassafras loam and the plot area was about 2 acres. Although there were inconsistencies in the yields, as evidenced by the green weights, there was no indication that the spent-acid superphosphate had any adverse effect on plant growth (Table 7).

TABLE 7.—*Effects of superphosphates on yields of silage corn, New Jersey Agricultural Experiment Station.*

Treatment*	Average yield per acre, lbs.†
P_C‡	34,560
P_S‡	42,210
P_C§	42,710
P_S§	37,220

*5–10–10 mixture, composed of $(NH_4)_2SO_4$, superphosphate, KCl, and dolomitic limestone applied at rate of 800 pounds per acre.
†Green weight; three replications.
‡500 pounds of mixed fertilizer per acre applied broadcast and 300 pounds along the row.
§700 pounds of mixed fertilizer per acre applied broadcast and 100 pounds along the row.

SUMMARY

As shown by field experiments in Connecticut, Iowa, Maine, Maryland, Michigan, and New Jersey, superphosphates made, respectively, with clear sulfuric acid and with spent sulfuric acid from the manufacture of high-octane gasoline by the alkylation process, had similar effects on the growth of alfalfa, barley, oats, oat hay, potatoes, silage corn, sweet corn, Sudan grass, sugar beets, and wheat.

THE TOLERANCE OF FLAX TO SALINE CONDITIONS: EFFECT OF SODIUM CHLORIDE, CALCIUM CHLORIDE, AND SODIUM SULFATE[1]

H. E. HAYWARD AND WINIFRED B. SPURR[2]

THE demand for linseed oil and flax fiber under wartime conditions has resulted in a marked increase in acreage of flax in the western states. On the basis of 1941 figures[3] California and Montana harvested over a tenth of the total acreage in the United States, and Arizona, Washington, Oregon, and Idaho reported acreages ranging from 2,000 to 14,000 acres. In the Imperial Valley of California the acreage of flax has increased[4] from about 20,000 acres harvested in 1936, to 106,000 acres in 1942, and the acreage for 1943 was approximately 145,000 (9).[5] This extension of acreage has resulted in planting some flax on saline land. For this reason, it has seemed desirable to obtain more complete information on the effect of saline substrates on the vegetative growth of flax and the yield and oil content of the flax seed.

METHODS AND MATERIALS

The Punjab variety of flax was selected since it is planted almost exclusively in California and Arizona where winter flax is grown and where some districts have a well-developed soil salinity. The plants were grown under greenhouse conditions in sand cultures in 5-gallon jars which were equipped with automatic irrigators controlled by a time clock (5). Each culture was provided with a main reservoir and a smaller accessory one to control the amount of solution delivered at one irrigation. The combined capacity of the two reservoirs was 20 liters, and 6 liters were held by the sand.

The date of seeding in the Imperial Valley extends from about November 15 to December 15, although some late plantings were made up to January 1 during the 1942–43 season. In order to parallel as far as possible the flax-growing season in the Imperial Valley, plantings in these studies were begun the first week in December. The seeds were germinated between moist blotters and were then planted in the sand cultures on December 8. The seeds were arranged in a 6-inch circle, ¼ inch apart and ½ inch deep, and later were thinned leaving six plants approximately 3 inches apart which gave a spacing of plants in line with the recommendations of Dillman and Brinsmade (2).

SALT TREATMENTS

Thirteen treatments were used, a control or basal nutrient solution, 0.5 atmosphere osmotic concentration (Table 1), and three series of salt solutions adjusted

[1]Contribution from the U. S. Regional Salinity Laboratory; Bureau of Plant Industry, Soils, and Agricultural Engineering; Agricultural Research Administration; U. S. Dept. of Agriculture; Riverside, Calif. In cooperation with the eleven western states and the Territory of Hawaii. Received for publication October 25, 1943.

[2]Senior Plant Anatomist and Junior Botanist, respectively.

[3]Agricultural statistics for 1942. U. S. D. A.

[4]Personal communications from A. C. Dillman and L. G. Goar.

[5]Figures in parenthesis refer to "Literature Cited", p. 300.

TABLE 1.—*Composition of the control (basal nutrient) solution.*

	Ca	Mg	Na	K	Cl	NO_3	H_2PO_4	SO_4	Total
				M.E. per Liter					
Basal nutrient salts......	2.5	2.5	—	3.25	1.00	5.0	0.75	3.5	
Riverside tap water.....	1.4	0.23	1.51	0.05	0.45	—	—	0.75	
Total........	3.9	2.73	1.51	3.30	1.45	5.0	0.75	4.25	22.89
				P.P.M.					
Basal nutrient salts.......	50	30	—	127	36	310	71	168	
Riverside tap water.....	28	3	35	2	16	—	—	36	
Total........	78	33	35	129	52	310	71	204	912

Micro-elements: B, 0.5 p.p.m.; Mn, 0.5 p.p.m.; Fe, 1.0 p.p.m.

to 1.5, 2.5, 3.5, and 4.5 atmospheres by the addition of NaCl, $CaCl_2$, and Na_2SO_4, respectively, to the basal nutrient solution (Table 2).

TABLE 2.—*Salt additions to the basal nutrient solution.*

Total osmotic concentration, atm.	Added salts								
	NaCl series			$CaCl_2$ series			Na_2SO_4 series		
	M.E. per liter	P.p.m.	Conductance*	M.E. per liter	P.p.m.	Conductance	M.E. per liter	P.p.m.	Conductance
1.5..........	25	1,463	384	32	1,776	452	39	2,769	468
2.5..........	49	2,867	624	63	3,497	778	76	5,396	774
3.5..........	73	4,270	872	94	5,217	1,125	113	8,023	1,060
4.5..........	97	5,675	1,118	125	6,975	1,484	150	10,650	1,340

*Specific electrical conductance, $K \times 10^5 @ 25°C$, of basal nutrient solution plus added salt.

When the experiment was initiated, the cultures were brought up to total concentration by steps of 1 atmosphere daily over a period of 4 days, and the young plants were subjected to the final concentration by the time they were 7 cm tall. Although the concentration of the three series of solutions at a given osmotic concentration varied widely in terms of chemical equivalents, previous experiments at this laboratory have indicated that the comparative effect of different salts could be determined most validly on an isosmotic basis (6, 7, 10). Each treatment was replicated three times and the cultures were randomized in the experimental design (Fig. 1).

The pH values were maintained within the range 5.5 to 6.5 with additions of HNO_3. Specific electrical conductances of the solutions were run weekly and the osmotic concentration calculated by means of curves determined by Gauch and

Wadleigh (6) showing the interrelationship of conductivity and osmotic concentration for each of the series of salt solutions. Salt additions were made as necessary to maintain the NO_3 level and the required osmotic concentration of the culture solutions. Complete changes of solutions were made at 4-week intervals.

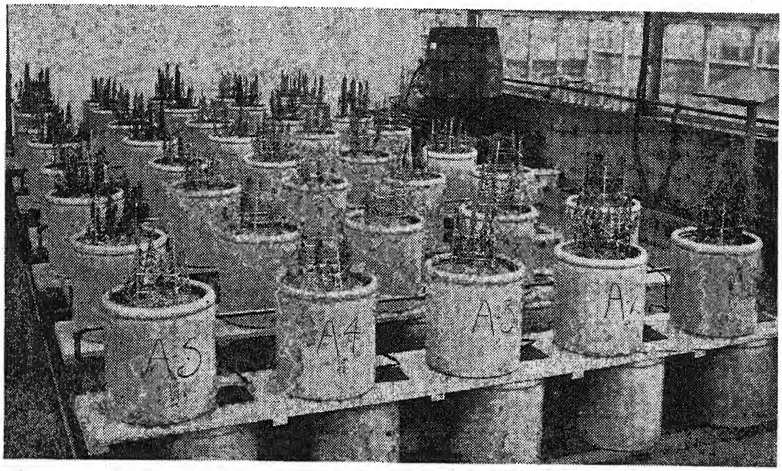


FIG. 1.—General view of the experimental setup. Photographed 38 days after planting.

RESULTS

VEGETATIVE RESPONSES

Vegetative response to the differential salt treatments was measured in terms of the height of the main stem and the green and dry weights of tops. The latter are discussed in connection with the harvest data. The growth of the main stems from the emergence of the seedlings to the time at which their elongation ceased is shown in Fig. 2 and Table 5. There was a marked inhibition in growth as the osmotic concentration of the substrate was increased regardless of the added salt used. The relative growth of representative plants in the three series is illustrated in Fig. 3.

The relative effect of the three salts when compared at isosmotic concentrations is shown in Fig. 4. In general, the curves are typical sigmoid growth curves with displacement to the right denoting plants on salt treatments and they give an index of the depression of the growth rate. The shape of the curves indicates that they fit very closely to theoretical formulation for exponential growth.

In terms of growth in height of the main stem, the 1.5 atm. treatments resulted in very slightly shortened stems as compared with the controls (Fig. 4). Until the last 3 weeks of the growing period, plants on the $CaCl_2$ substrate showed the least growth depression and those on the Na_2SO_4 the greatest; but as the plants under the control, $CaCl_2$ and NaCl treatments approached maturity there was a tendency for the Na_2SO_4 plants to catch up with them.

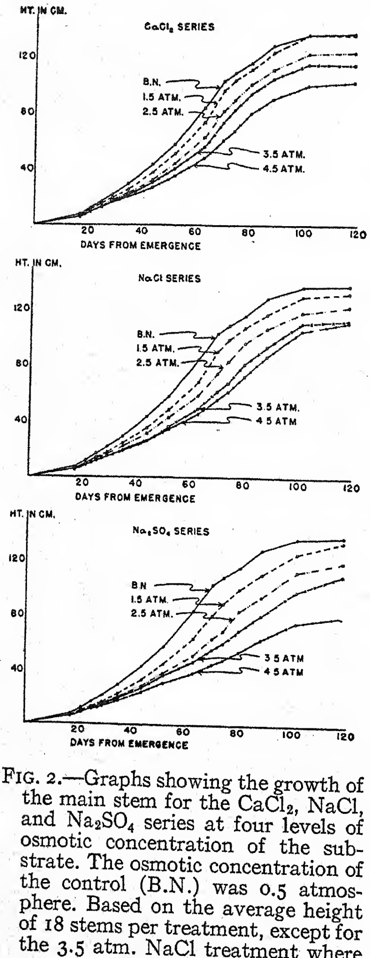


FIG. 2.—Graphs showing the growth of the main stem for the $CaCl_2$, NaCl, and Na_2SO_4 series at four levels of osmotic concentration of the substrate. The osmotic concentration of the control (B.N.) was 0.5 atmosphere. Based on the average height of 18 stems per treatment, except for the 3.5 atm. NaCl treatment where 12 stems were measured.

At the 2.5 atm. level, the relative inhibitive effect of the three salts was like that of the 1.5 atm. series, and a similar convergence of growth curves during the final weeks of growth was observed. In the Na_2SO_4 series, the response of the plants to the 3.5 and 4.5 treatments was somewhat different than that exhibited at the 1.5 and 2.5 levels. Thus the percentage depression under the Na_2SO_4 treatments was greater during the grand period of growth than for the plants in the two chloride series at these levels. Definite symptoms of chlorosis were observed at these concentrations under the Na_2SO_4 treatments and these were very pronounced at the 4.5 atm. level.

Considering the vegetative growth under the three salt treatments at all levels of osmotic concentration, it would appear that calcium chloride is less toxic than either of the sodium salts and that of the latter sodium sulfate is the more toxic. Although the growth rate under the Na_2SO_4 treatments were slowest during the period of normal vegetative development, rate of vegetative growth during the reproductive phase of the life cycle did not decrease as much as under the other salt treatments. This may be correlated with the large number of abortive embryos and low yield of seed produced by the sulfate plants at the 3.5 and 4.5 atm. concentrations which are reported under harvest data.

ANATOMICAL RESPONSES

High osmotic concentrations of the substrate may produce marked changes in the manner in which the tissues of a stem differentiate and the amount of tissue formed (7). The tissues of the median internode of the main stems of plants grown under the three salt treatments at 2.5 and 4.5 atm. osmotic concentration were compared histologically with those from control plants. The stems of plants grown in the 4.5 atm. substrates were smaller than those of the control plants,

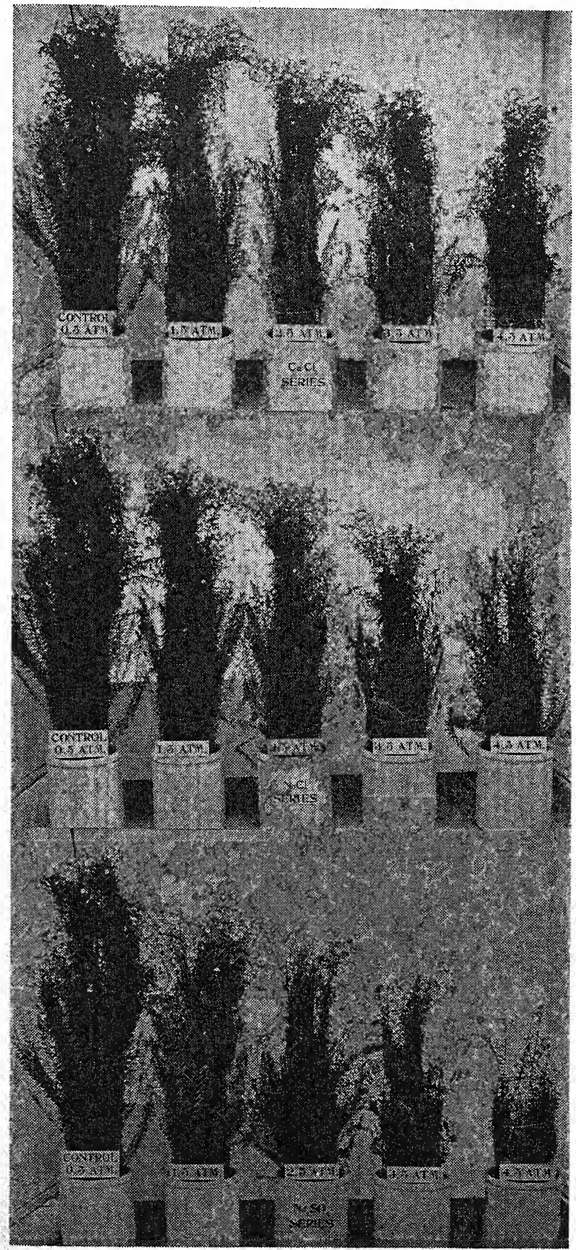


FIG. 3.—Effect of $CaCl_2$, NaCl, and Na_2SO_4 at four levels of osmotic concentration on the vegetative growth of flax. The plants in the 4.5 atm. culture in the Na_2SO_4 series were very chlorotic. Photographed March 17, 1943, when all cultures, except the 3.5 and 4.5 treatments in the Na_2SO_4 series, were in full bloom, 96 days after planting.

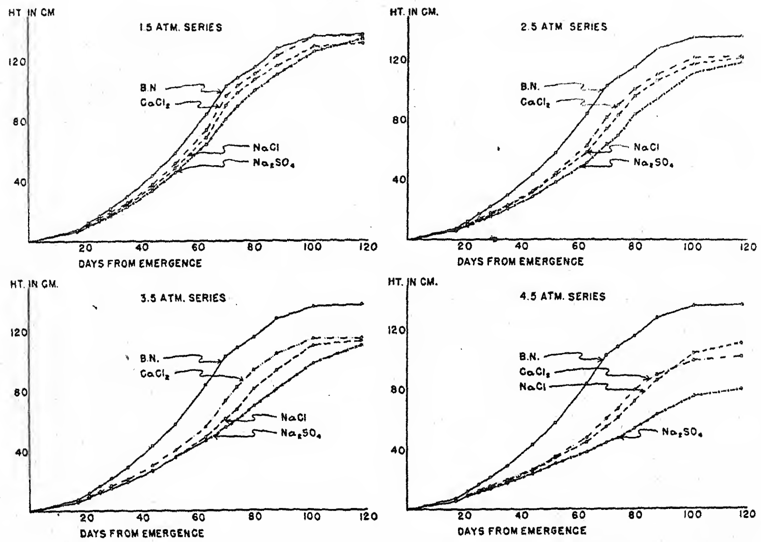


FIG. 4.—Graphs showing relative effect of isosmotic concentrations of $CaCl_2$, NaCl, and Na_2SO_4 on growth in height of the main stem at the 1.5, 2.5, 3.5, and 4.5 atm. levels. The control (B.N. –0.5 atm.) curve is shown in each graph to indicate the increasing degree of divergence between it and those of the salt treatments as the osmotic concentration of the substrate is increased.

and the stems from the 2.5 atm. treatments were intermediate in diameter (Table 3).

This reduction in diameters of stems is related to the decrease in the rate of formation and the size of the cells of the secondary xylem. At 2.5 atm. osmotic concentration, the cambium is less active and fewer vessels and wood parenchyma cells are formed by it than in the controls and this cambial inhibition is more marked at the 4.5 atm. level. The reduction in size of cells is not pronounced under the 2.5 atm. treatments but is marked at the 4.5 atm. level (Table 3). This is especially noticeable in comparing the size of vessels and phloem fibers of the control plants with those of the highest salt treatments (Fig. 5).

The effect of salt treatments on fiber development is of interest. Normally, the first phloem fibers (the fibers of commerce) are differentiated in the outermost layer of the phloem zone next to the endodermis (4). Later ones are formed centripetally, and at maturity there is a discontinuous ring of fibers several cells in width (Fig. 5, A). Under high salt treatments, the phloem fibers are fewer in number and reduced in size, although the relative thickness of the wall as compared with the size of the fiber cell may be greater than in the control plants. In addition, the width of the phloem zone may be reduced. It was also observed that there was a tendency to form wood fibers under high NaCl treatments that was not as pronounced at comparable levels of $CaCl_2$ and Na_2SO_4 (Fig. 5, B and Fig. 6, A and B). The width of the cortex and the size of the cortical cells was not affected

by treatment as much as was the secondary xylem and phloem tissue, but there was a marked reduction in the diameter of the pith at the 4.5 atm. level, especially under the sulfate treatment (Table 3).

TABLE 3.—*Effect of osmotic concentration of the substrate on the diameter and growth of tissues of the main stem.**

Treatment salt	Osmotic conc., atm.	Diameter of stem, mm	Width of cortex, μ	Width of xylem, μ	Diameter of pith, μ	No. of phloem fibers	Diameter of fibers, μ†
Control (basal nutrient)....	0.5	4.1	65	710	1,940	997	63
Calcium chloride.........	2.5	3.2	62	524	1,575	848	50
	4.5	2.7	62	433	1,280	733	49
Sodium chloride	2.5	3.7	55	722	1,605	904	61
	4.5	2.9	54	470	1,290	584	51
Sodium sulfate	2.5	3.3	55	587	1,465	799	58
	4.5	2.2	60	327	970	485	46

*These data are for the median internode of the main stem and are averages of measurements or counts of three stems.
†Average of maximum diameters—20 largest fibers per stem.

The histological evidence and the data on growth in height of the main stem indicate that high concentrations of salt in the substrate inhibit the activity of both primary and secondary meristems with resultant reduction in height and diameter of stems. As with height, the diameter of stems at isosmotic concentrations was smallest under the Na_2SO_4 treatments, but NaCl was slightly less inhibitive with respect to cambial activity than calcium chloride.

FLOWERING AND FRUITING RESPONSES

In general, all salt treatments retarded flower bud development, anthesis of flowers, and rate of setting of bolls (Fig. 7). Flower buds appeared on the control plants from 13 to 17 days earlier than on plants under the highest salt treatments. Anthesis was similarly affected, the spread in time of first blooming between the control plants and those on 4.5 atm. substrates ranging from 14 to 18 days. The rate of setting of bolls was determined on an arbitrary base of 50 bolls per culture and a lag of 3 to 11 days was observed between the controls and the most concentrated salt treatments. At equivalent osmotic concentrations, the development of flowers and bolls was least inhibited by $CaCl_2$ and most retarded by the sodium salts (Fig. 7).

HARVEST DATA, YIELD, AND QUALITY OF SEED

The crop was harvested May 25, 1943, 165 days after planting. This compares with a normal period from seeding to ripening of 177 days at El Centro, Calif. (3). In general, all plants were in the yellow stage of maturity with 75 to 90% of the bolls yellow to yellow-brown, although the plants under the 2.5 and 3.5 atm. sodium sulfate treat-

ments were somewhat less ripe than the other cultures, and the 4.5 atm. sodium sulfate plants were very chlorotic (1). The plants were cut off at the level of the cotyledonary node and were spread out on benches in the greenhouse to dry. One week later the air-dry weight of tops was determined, the bolls threshed, and the seed cleaned and weighed. The harvest data are shown in Table 4.

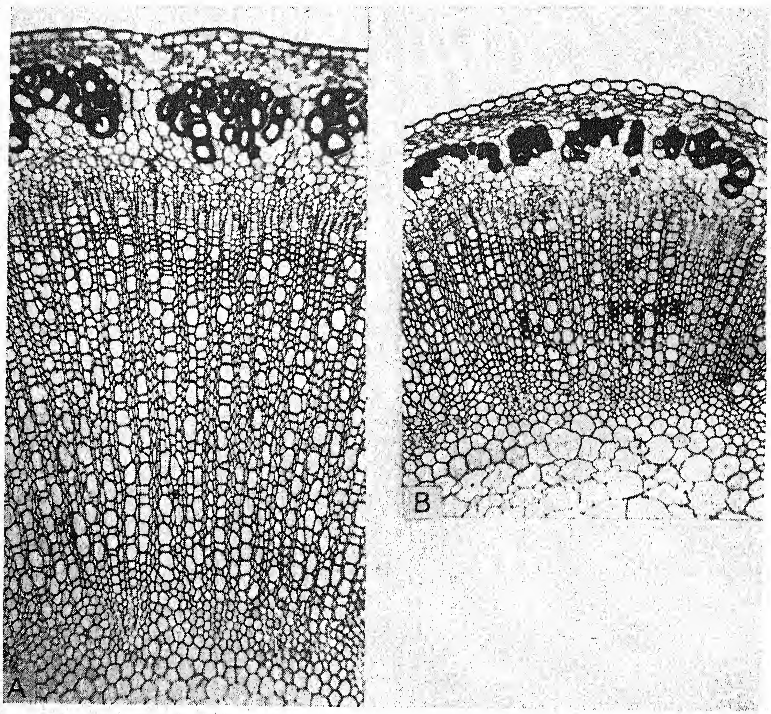


FIG. 5.—A, Transection of a median internode of the main stem of flax from a control plant (0.5 atm. osmotic concentration), showing development of phloem fibers and amount of secondary thickening of the axis. B, Transection of a corresponding internode from a plant grown on the NaCl substrate at 4.5 atm. osmotic concentration. The formation of wood fibers in the xylem region is shown. Comparison with A indicates the inhibitive effect of high concentration of salt on cambial activity and size of cells. Photomicrographs at same magnification.

In each series there was a reduction in green and dry weight of tops as the concentration of the substrate was increased. In the NaCl series there was a sharp break between the 2.5 and 3.5 atm. levels, and the 4.5 atm. treatment gave essentially the same yield as the 3.5 atm. culture. The 1.5 atm. $CaCl_2$ treatment produced tops that were somewhat heavier than the controls on a green weight basis and in the other three treatments of this series the reduction in green weight of tops at the higher osmotic concentrations was greater than in the NaCl series. In the Na_2SO_4 series reductions in top weights were ap-

proximately like those in the other series except at the 4.5 atm. level where a more pronounced reduction was evident. The plants under this treatment were very much smaller, chlorotic, and produced few flowers and no mature seed.

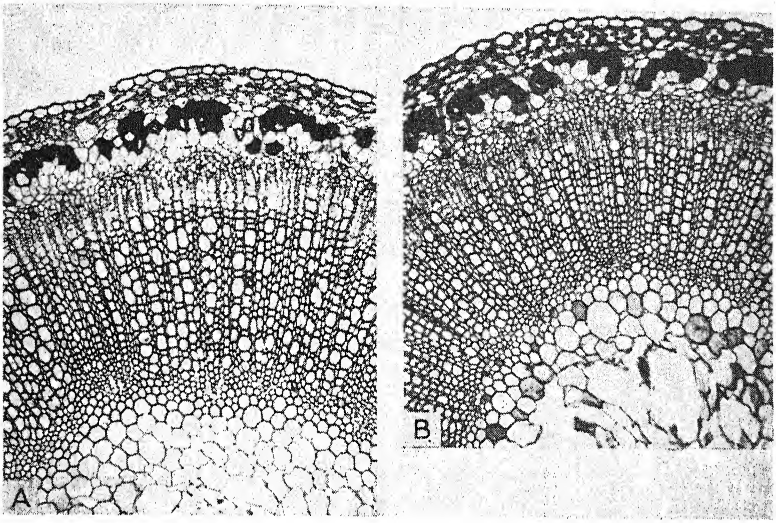


FIG. 6.—Transections of median internodes of main stems of flax from plants grown on calcium chloride (A) and sodium sulfate (B) substrates at 4.5 atm. osmotic concentration, showing development of phloem fibers and amount of secondary thickening. Compare with Fig. 5, A and B. which are at the same magnification.

The relative and actual yields of seed by treatments are shown in Table 4. Yields were greatly reduced when the osmotic concentration of the substrate exceeded 2.5 atm. regardless of the salt used. Yields at equal osmotic concentrations were slightly better in the $CaCl_2$ series at the 1.5, 2.5, and 3.5 atm. levels than for the other two series, and the 1.5 atm. $CaCl_2$ treatment gave a somewhat larger yield than the control. The yields under the Na_2SO_4 treatments were significantly lower than comparable treatments with the chloride salts, and no mature seeds were produced at the 4.5 atm. level. In this treatment, flowers were produced and fruit development initiated, but the seed failed to develop. The small bolls were shrunken at maturity and usually contained a few flat immature or aborted seeds.

Samples of seed from each treatment were analyzed for oil content, iodine number, and crude protein, and the seed size was determined (Table 5).[6] The analyses indicate that the effect of the salt treatments

[6]Analyses were made at the laboratory of the Division of Cereal Crops and Diseases, University Farm, St. Paul, Minn., maintained in cooperation with the Division of Biochemistry, University of Minnesota. We are indebted to Mr. A. C. Dillman, Associate Agronomist in charge of Flax Investigations who made arrangements for the analytical work and to Mr. J. A. Schricker, Assistant Chemist, who directed the analytical work. Thanks are due Mr. L. G. Goar in charge of the Imperial Valley Field Station of the University of California for supplies of flaxseed and data concerning the 1943 crop.

on quality of seed is of questionable significance. The oil content was not appreciably affected by treatment, but the iodine number was slightly lower at the high salt levels. Crude protein was about 3% higher at the high salt levels than in the controls and seed size showed no consistent relationship to treatment.

TABLE 4.—*Height of main stem, green and dry weights, percentage dry weight, and relative yield of seed.*

Osmotic concentration, atm.	Height of main stem, cm*	Green weight of tops, grams*	Dry weight of tops, grams*	Percentage dry weight	Relative yield of seed†
		Control (Basal Nutrient)			
0.5 atm.	138	168.3	69.0	41.0	100
		NaCl Series			
1.5	132	162.1	62.5	38.6	90
2.5	123	151.3	55.8	36.9	83
3.5	113	111.0	38.8	35.0	65
4.5	112	113.3	39.5	34.9	67
		$CaCl_2$ Series			
1.5	137	173.6	66.1	38.1	106
2.5	124	132.8	50.1	37.7	86
3.5	114	107.0	42.2	39.4	75
4.5	103	72.5	30.2	41.7	47
		Na_2SO_4 Series			
1.5	134	151.6	63.0	41.6	81
2.5	120	140.5	49.8	35.4	67
3.5	110	119.5	38.9	32.6	38
4.5	81	49.6	14.8	29.8	0

*Average per plant.
†These figures also represent the actual yield per culture of six plants in grams.

DISCUSSION

The data on vegetative responses to high osmotic concentrations of sodium chloride, sodium sulfate, and calcium chloride indicate that the flax plant is moderately tolerant to salt. In general, the effect of the three salts on the vegetative responses of the flax plant is of the same order at equal osmotic concentrations, but at the 4.5 atm. concentration sodium sulfate induced a more pronounced inhibition of growth. Anatomical analysis of the tissues of the stems grown under the control, 2.5, and 4.5 atm. treatments supports the evidence obtained from vegetative responses and emphasizes the inhibitive effect of high salt concentrations on the meristematic tissues of the plant.

Reasonably good yields may be expected if the osmotic concentration of the substrate does not exceed 2.5 atm. and poor yields or complete failure of the crop are probable if the osmotic concentration exceeds 4.5 atm. These conclusions, based on plants grown in sand cultures, correlate well with observations made at the Imperial Valley Field Station, El Centro, Calif. Soil samples from the first 6

inches were taken from the experimental plots where the flax was growing satisfactorily and from spots where it had made little growth or had failed to germinate (Fig. 8). The osmotic concentration of the saturation extract was 0.8 atm. in the former and 5.0 atm. in the latter. When calculated on the basis of the moisture equivalent, these values are approximately 1.5 and 10.0 atm., respectively. In the saturation extract of the more saline soil, the cations determined in equivalents per million were calcium, 65; magnesium, 34; and sodium, 57; and the principal anions were chloride, 112, and sulfate 31.

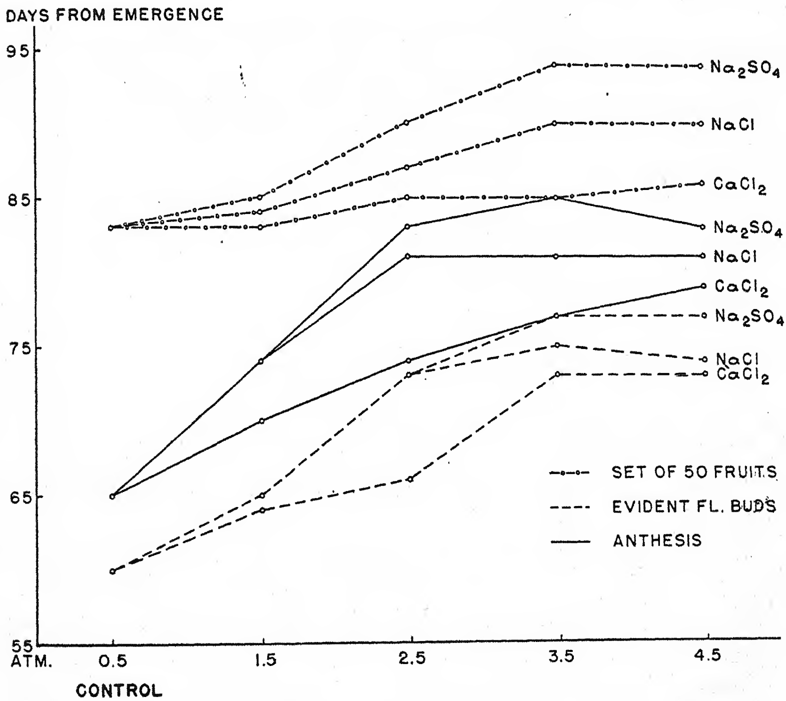


FIG. 7.—The effect of the three salt treatments at four levels of osmotic concentration on the basis of development of flower buds, anthesis of flowers, and set of bolls.

Unlike yield, quality, expressed in terms of seed size, oil content, iodine number, and percentage crude protein, was affected to only a slight degree by the salt treatments, and in most comparisons the difference could not be regarded as significant. There was a tendency toward a lower iodine number under the high salt treatments which amounted to about a 5% reduction in the Na_2SO_4 treatment at 3.5 atm. osmotic concentration. All values obtained from the sand culture experiments were lower than those for Punjab flax grown under field conditions in the Imperial Valley of California. Seven-year averages for the valley were weight per 1,000 seeds, 6.2 grams; oil content, 39.1%; iodine number, 186; and crude protein, 35.8% (3). Compar-

TABLE 5.—*Flaxseed and linseed oil analyses, average of three replicates.*

Osmotic concentration, atm.	Seed size*	Oil content, %†	Iodine No.‡	Crude protein, %§
	Control (Basal Nutrient)			
0.5	4.63	35.0	167	33.9
	NaCl Series			
1.5	4.74	35.2	165	34.9
2.5	4.79	35.1	164	36.2
3.5	4.66	34.8	163	37.7
4.5	4.75	35.4	162	36.7
	$CaCl_2$ Series			
1.5	4.78	35.7	165	35.1
2.5	4.60	36.2	164	35.1
3.5	4.70	35.6	162	36.5
4.5	4.27	34.6	163	36.7
	Na_2SO_4 Series			
1.5	4.48	34.4	166	35.2
2.5	5.19	35.0	160	37.0
3.5	4.75	34.6	158	36.4
4.5**	—	—	—	—

*Expressed as weight of 1,000 seed in grams.
†Oil content based on 8% moisture in flaxseed, determined by extraction method.
‡Iodine number of oil determined by refractometric method.
§Crude protein based on 11% moisture and 4% oil in the meal.
**No seed available for analyses.

able figures for the control plants grown in the greenhouse at Riverside, Calif., are 4.63 grams, 35.0%, 167, and 33.9%, respectively. The differences in seed size are undoubtedly due in part to the much

FIG. 8.—Experimental stand of flax at the Imperial Valley Field Station of the University of California, El Centro, Calif., showing the effect of saline soil. Soil samples from the bare spots in the foreground indicated a soil moisture concentration of 10 atm. when calculated on the basis of the moisture equivalent. In the productive spots, the concentration was approximately 1.5 atm. Photograph by H. G. Gauch.

greater number produced in the greenhouse cultures. Owing to the manner of growing the plants in groups of six per culture, there was a much greater development of lateral branches and infloresences (2). Other factors which may be involved are higher temperatures and higher transpiration and the relatively low NO_3 level that was maintained during the period of seed development.

The lower values for oil content and iodine number are probably related to high temperature. Dillman and Hopper (3) have found a high negative correlation between excess temperature and production of oil and its iodine number. They state that, "The total excess temperature above 90° F during the seed-filling period should reflect most accurately the injurious effect of extremely high temperature on the yield and quality of flaxseed." Normal April temperatures for El Centro over a 9-year period were average mean, 70°F; average maximum, 86°F; and total degrees in excess of 90°F ranged from 18 to 129. April temperatures in the greenhouse were slightly higher than those for El Centro, and for the 25 days in May prior to the harvest were considerably higher, *viz.*, average mean, 75.4°F; average maximum, 92.7°F; degrees in excess of 90°F, 109.

SUMMARY

Punjab flax was grown in sand cultures under greenhouse conditions. Thirteen treatments were used including a control or basal nutrient solution (0.5 atm. osmotic concentration) and three series of salt solutions adjusted to 1.5, 2.5, 3.5, and 4.5 atm. osmotic concentration by the addition of NaCl, $CaCl_2$ and, Na_2SO_4, respectively, to the basal nutrient solution.

The vegetative responses of the flax plant to high osmotic concentrations of these salts indicate that it is moderately tolerant to saline conditions. In general, the effect of the three salts on vegetative growth is of the same order at equal osmotic concentrations, but at 4.5 atm. sodium sulfate induced a more pronounced inhibition than the chloride salts.

The reduction in height and diameter of stems under high salt treatments is correlated with marked changes in the differentiation of the stem tissues. At high concentrations of salt, the cambium is less active and the cells of the secondary xylem are smaller than in the control plants. The number and diameter of the phloem fibers is also less in plants grown in substrates of high osmotic concentration.

As compared with controls, substrates of high osmotic concentration delayed anthesis of flowers and setting of bolls from 5 to 18 days. At equal osmotic concentrations of the three salts the inhibitive effect was most pronounced with sodium sulfate, intermediate with sodium chloride, and least with calcium chloride.

Yield of seed was reduced by high salt concentrations in all series. In general, calcium chloride was less inhibitive to seed production than equal osmotic concentrations of sodium sulfate and, with one exception, the effect of sodium chloride was intermediate. At high concentrations of salt (3.5 and 4.5 atm.) relative yields were reduced from 25 to 62% and no mature seed were produced at the highest concentration of sodium sulfate.

The effect of the treatments on quality of seed, expressed in terms of seed size, oil content, iodine number, and percentage crude protein, was of questionable significance.

LITERATURE CITED

1. DILLMAN, A. C. Daily growth and oil content of flaxseeds. Jour. Agr. Res., 37:357–377. 1928.
2. ——— and BRINSMADE, J. C., Jr. Effect of spacing on the development of the flax plant. Jour. Amer. Soc. Agron., 30:267–286. 1938.
3. ——— and HOPPER, T. H. Effect of climate on the yield and oil content of flaxseed and on the iodine number of linseed oil. U.S.D.A. Tech. Bul. 844. 1943.
4. ESAU, KATHARINE. Vascular differentiation in the vegetative shoot of linum: III. The origin of the bast fibers. Amer. Jour. Bot., 30:579–586. 1943.
5. GAUCH, H. G., and WADLEIGH, C. H. A new type of intermittently-irrigated sand culture equipment. Plant Physiol., 18:543–547. 1943.
6. ———, ———. The influence of high salt concentrations on growth of bean plants. Bot. Gaz. (In press)
7. HAYWARD, H. E., and LONG, E. M. Anatomical and physiological responses of the tomato to varying concentrations of sodium chloride, sodium sulfate and nutrient solutions. Bot. Gaz., 102: 437–462. 1941.
8. ——— and SPURR, WINIFRED B. Effects of osmotic concentration of substrate on the entry of water into corn roots. Bot. Gaz., 105:152–164. 1943.
9. Imperial County Flax Enterprise Efficiency Study. Agr. Ext. Ser. El Centro, California, 1936.
10. MAGISTAD, O. C., AYERS, A. D., WADLEIGH, C. H., and GAUCH, H. G. Effect of salt concentration, kind of salt, and climate on plant growth in sand cultures. Plant Physiol., 18:151–166. 1943.
11. U.S.D.A., Agricultural Statistics, 1942.

EIGHT YEARS' RESULTS ON THE EFFECTIVENESS OF FERTILIZATION AND MANAGEMENT IN INCREASING THE PRODUCTION OF PERMANENT PASTURES[1]

H. L. Ahlgren, I. W. Rupel, G. Bohstedt, and E. J. Graul[2]

THERE is available in the pasture research literature of the world (9, 10)[3] a vast body of data attesting to the relatively low production of most permanent grasslands. The low productivity characteristic of these grasslands has been variously attributed to the single or combined effects of lack of fertility, improper grazing management, insect injury, drought, and in the case of woods pastures, to shading.

Fortunately, considerable evidence has gradually been accumulated in the development of a better understanding of the underlying causes which affect the production of permanent grasslands. Small plot "lawn-mower" investigations and studies conducted under actual grazing conditions have contributed valuable information of direct and immediate practical importance in the field of pasture improvement. It must be emphasized, however, that there are still many unsolved problems.

It is clear from the literature that the yields of permanent grasslands can be materially and profitably increased provided proper treatments are given them. Further, it has been shown that in addition to increased yields and better quality of forage, improved pastures provide the cheapest and most economical source of feed on the farm, and offer an effective and realistic means of controlling soil losses due to erosion. Occasional studies (12) appear to suggest that the production of improved permanent pastures may compare favorably with that of cultivated crops on soils of comparable fertility. The gradual and progressive development of an understanding of the requirements of grasslands and of their value and importance not only as an excellent source of forage but also in soil improvement and

---

[1]Contribution No. 189 from the Department of Agronomy, University of Wisconsin, Madison, Wis. Cooperative investigations of the Departments of Agronomy, Dairy Husbandry and Soils of the Wisconsin Agricultural Experiment Station, and the Bureau of Plant Industry, Soils and Agricultural Engineering, U. S. Dept. of Agriculture, Washington, D. C. Published by permission of the Director of the Wisconsin Agricultural Experiment Station. Received for publication October 29, 1943.

[2]Associate Professor of Agronomy, Associate Professor of Dairy Husbandry, Professor of Animal and Dairy Husbandry, and Professor of Soils, respectively, Wisconsin Agricultural Experiment Station. Assistance in carrying forward the agronomic phases of the study was provided by the late F. W. Tinney, Assistant Agronomist, Bureau of Plant Industry, U. S. Dept. of Agriculture, during the period 1936–39. Thanks are due Doctor O. S. Aamodt, Head Agronomist in Charge, Division of Forage Crops and Diseases, Bureau of Plant Industry, Soils, and Agricultural Engineering, U. S. Dept. of Agriculture, and Professor L. F. Graber, Department of Agronomy, Wisconsin Agricultural Experiment Station, for many suggestions in connection with the study. Gratitude is also due to Messrs. G. M. Werner and C. E. Zehner, Assistant Professor and Instructor of Dairy Husbandry, respectively, Wisconsin Agricultural Experiment Station, for assistance with certain of the livestock phases of the study.

[3]Figures in parenthesis refer to "Literature Cited", p. 315.

soil conservation has found recent expression (2) in a type of land use commonly referred to as "grassland agriculture".

Unfortunately, the results which are obtained in any given region or area may not be directly applicable to other regions or even to specific areas within the region. Diverse soil and climatic conditions and differences in systems of farming between regions and even within regions frequently necessitate studies designed specifically to provide information needed in the solution of problems peculiar to the region or area.

The studies herein described are a result of cooperative investigations between the Departments of Agronomy, Dairy Husbandry, and Soils of the Wisconson Agricultural Experiment Station. These studies were initiated in 1934 and were designed specifically to obtain exact information relative to the effects of management and fertilization on the production of permanent pastures under actual grazing conditions. The soil used in this study was comparable in fertility with that used for cultivated crops on the University Hill Farms at Madison, Wis.

PLAN OF EXPERIMENT

SEEDING AND FERTILIZING

Four permanent pastures which are referred to hereafter as fields 1, 2, 3, and 4 were established from seeding on a gently rolling Miami silt loam on the University South Hill Farm in the spring of 1934. A detailed soil analysis was made of each of the four fields prior to seeding. Superphosphate and muriate of potash were applied to fields 1, 2, and 3 in such a manner as to raise the available phosphorus and available potash content of the soil to the same approximate level in the three fields. Fields 1, 2, and 3 were fertilized with muriate of potash (50% K_2O) at the rate of 100 pounds per acre. Superphosphate (20% P_2O_5) was applied to fields 1, 2, and 3 in amounts varying from 400 to 590 pounds per acre. Superphosphate was also applied to the north one-third of field 4 at the rate of 125 pounds per acre. In addition, barnyard manure was applied at the rate of 8 tons per acre to the south two-thirds of the field. Ground limestone was applied to all fields at the rate of 1½ tons per acre.

A mixture composed of 15 pounds of Kentucky bluegrass, *Poa pratensis*, 4 pounds of red top, *Agrostis alba*, 6 pounds of timothy, *Phleum pratense*, 3 pounds of medium red clover, *Trifolium pratense*, 3 pounds of alsike clover, *T. hybridum*, and 2 pounds of white clover, *T. repens*, was seeded at the rate of 35 pounds per acre in fields 1, 2, and 3 on May 8 and 9, 1934. Sixteen pounds of the above mixture together with 12½ pounds of Cossack alfalfa, *Medicago sativa*, and 4 pounds of common biennial white blossom sweet clover, *Melilotus alba*, were seeded per acre in field 4 at the same time. Oats was seeded at the rate of 1 bushel per acre in each of the four fields.

The entire seeding with the exception of that in field 4 was destroyed by drought during the early portion of the 1934 growing period. Fields 1, 2, and 3 were reseeded in the fall of 1934 at which time a mixture of 14 pounds of Kentucky bluegrass, 4 pounds of redtop, and 10 pounds of timothy was applied at the rate of 28 pounds per acre. A mixture of 3 pounds of medium red clover, 3 pounds of alsike clover, and 2 pounds of white clover was applied broadcast on the soil surface at the rate of 8 pounds per acre to fields 1, 2, and 3 on April 2, 1935. An additional

9 pounds of sweet clover were sown per acre in field 4 on March 20, 1935. Excellent stands of all grasses and legumes were obtained.

Calcium cyanmid was applied in early April to fields 2 and 3 at the rates of 150 and 240 pounds per acre, in 1935 and 1936, respectively, and at the rate of 250 pounds per acre each year thereafter.

Much of the alfalfa originally present in field 4 had been eliminated in previous grazing by the end of the 1937 growing period. However, it was assumed on the basis of previous experience that the beneficial effects of the alfalfa on the growth of the Kentucky bluegrass would not be fully dissipated until the end of the 1940 growing period. In order to utilize this field for experimental grazing each year and to complete renovation of all three paddocks by the end of the 1940 growing period, one paddock was renovated with alfalfa according to the procedure developed by Graber (5) each year during the period 1938 to 1940, inclusive. Calcium metaphosphate (63% P_2O_5) and muriate of potash (50% K_2O) were applied in early spring prior to seeding to two of the paddocks at the rates of 130 and 200 pounds per acre, respectively. The remaining paddock was fertilized in early spring prior to seeding with superphosphate (45% P_2O_5) and muriate of potash (50% K_2O) at the rates of 180 and 200 pounds per acre, respectively. Alfalfa (½ Ladak and ½ Grimm or Cossack) was seeded at the rate of 12 to 13 pounds per acre in each paddock in early spring during the year of renovation.

Calcium metaphosphate was applied broadcast to fields 1, 2, and 3 at the rate of 125 pounds per acre in April and May of 1939.

GRAZING MANAGEMENT

Grazing was deferred until August 16 in 1935 to permit the grasses and legumes to become well established. All fields were cut for hay during the period July 6 to 19. The pastures were grazed thereafter in the manner and according to the procedure given below. Fields 1 and 2 were grazed continuously until the forage had been completely utilized. Fields 3 and 4 were grazed rotationally. Each of these fields was sub-divided by cross fencing into three 3-acre paddocks. The cattle grazed the sub-divisions within each of these fields in succession. The frequency with which the cattle were moved from one paddock to another in the rotationally grazed fields was determined by the rate of growth of the forage and the length of time needed to graze most of the forage down to a height of 2 to 3 inches. Grazing was not uniform in either the continuously or rotationally grazed fields, although there was a tendency for a more uniform type of grazing and for more complete utilization of the forage in fields 3 and 4 which were rotationally grazed than in fields 1 and 2 which were continuously grazed. The pastures were mowed each year at the end of the first grazing period to permit of a more uniform regrowth. The droppings were scattered by hand in late October the first year and thereafter with a chain harrow.

The various paddocks comprising field 4 were grazed moderately in August only of the year in which they were renovated in order to assure the successful re-establishment of the alfalfa.

All of the experimental fields were reduced in size from 9 to 6 acres in the spring of 1940 to make better use of available livestock facilities. Fields 3 and 4 were each sub-divided into three 2-acre paddocks at this time.

Dairy cows were used for grazing the fields in 1935, 1936, 1937, and 1940. Dairy heifers were utilized in 1938 and 1939 and a mixed herd of dairy heifers and cows grazed the fields in 1941. The cattle were allocated according to the estimated

production of the fields and in such a manner that approximately the same length of time was required for the removal of the forage from each of the fields. The cows were divided into four groups which were as comparable as possible with respect to milk production, stage of lactation, age, and weight. Likewise, the heifers were divided into four similar age and weight groups. One of each of the four groups of livestock was placed in each of the fields at the beginning of the grazing season. They were not removed from these fields except for milking and weighing or when there was no forage available for grazing. Whenever the forage in any one of the four fields had been adequately utilized, the cattle were removed to supplementary pastures where they remained until the experimental fields had recovered sufficiently so that grazing could be resumed. The initial grazing procedure was duplicated insofar as possible each year.[4] Supplementary feed was provided in varying amounts to the milking cows, although the average amount fed per cow was the same for each field. The actual amount fed each cow was determined by the milk production. Records were kept of all supplementary feed consumed by the livestock and necessary deductions were made in computing total digestible nutrients produced by the experimental fields. The daily milk production of each cow was determined. Aliquot samples of milk were taken at the time of each milking for butterfat determinations. Gains or losses in live weight were determined from weighings made on 3 consecutive days at the beginning and end of any grazing period and at bi-monthly intervals throughout the season. Averages of the three weighings were utilized in computing gains or losses in live weight.

METHODS OF DETERMINING YIELD AND BOTANICAL AND CHEMICAL COMPOSITION OF FORAGE

During 1935, the yield and botanical and chemical composition of the forage produced in the four fields were determined by periodic sampling of permanently enclosed square rod areas. Three square rod areas were located in each field. This method of sampling was believed to be unreliable and was abandoned in favor of the technic described below.

Excepting in 1935, movable wire cages each $4 \times 4 \times 1\frac{1}{2}$ feet in size were used to determine yields of dry matter of the experimental fields. Eighteen wire cages were distributed at random in fields 1 and 2, and six cages on each of the paddocks in fields 3 and 4. Forage was harvested beneath the cages in fields 3 and 4 in a manner to approximate the grazing at the end of each grazing period. The forage beneath one third of the cages in fields 1 and 2 was harvested in a manner approximating the grazing whenever grazing had been completed in one of the paddocks in field 3. Cages were moved to new areas selected at random immediately following each harvest. Representative samples were taken of the forage harvested beneath each cage for moisture and dry matter determinations. Three representative samples approximately a pound each in size were taken on each harvest date from a composite of the forage harvested beneath six cages for subsequent botanical and chemical analyses. Analyses for crude protein were according to the A.O.A. C. method (1). The actual yields of forage provided by the species comprising the sward were determined by hand separations of samples taken on each harvest date. A botanical analysis was not made in the experimental fields in 1942

[4]The grazing management accorded the pastures in 1942 was similar to that used during the period 1935 to 1941, inclusive. However, suitable experimental cattle were not available and for this reason the number of grazing days obtained and total digestible nutrients provided by the pastures are not reported for 1942.

since previous data had shown that there was little change in the botanical composition of the fields after 1939.

EVALUATION OF PASTURES

The four experimental fields were evaluated on the basis of (a) yields of dry matter and crude protein, (b) grazing days, and (c) total digestible nutrients. These fields were managed, fertilized with calcium cyanamid, and renovated according to the following procedure:

Field 1. Continuously grazed.
Field 2. Continuously grazed and fertilized annually with calcium cyanamid.
Field 3. Rotationally grazed and fertilized annually with calcium cyanamid.
Field 4. Rotationally grazed. Alfalfa was maintained in the sward by renovation. One third of the area of this field was renovated each year during the period 1938 to 1940, inclusive. Yields of dry matter, crude protein, total digestible nutrients, and grazing days are reported as averages for the entire area of 9 acres in 1938 and 1939 and on the basis of 6 acres in 1940.

CLIMATIC CONDITIONS

A wide range of climatic conditions prevailed during the 9 years the investigations were in progress. The actual and average monthly rainfall for the growing period of each year is given in Table 1. It is apparent from these data that rainfall was considerably below average in 1934, 1935, 1936, and 1939. Rainfall was considerably above average in 1938 and 1941, although the distribution was poor in both years. In general, climatic conditions were least favorable for growth of forage in 1934, 1936, and 1939 and most favorable for growth in 1938 and 1942. The spring and summer periods of 1936 were characterized by unusually severe heat and drought.

TABLE 1.—*Average monthly rainfall together with the actual monthly rainfall for the period April 1 to October 31, inclusive, at Madison, Wis.**

Month	1934	1935	1936	1937	1938	1939	1940	1941	1942	Av.
April	1.08	1.82	0.95	4.40	1.89	3.16	2.42	1.24	1.24	2.77
May	0.82	3.09	0.79	1.81	4.48	1.64	3.39	5.82	4.03	3.85
June	2.77	4.94	2.24	3.33	4.33	2.33	4.95	4.19	3.21	3.76
July	5.42	2.49	0.99	1.34	3.76	1.64	3.38	1.08	3.79	3.88
Aug.	2.21	4.22	5.97	1.18	5.31	2.61	6.15	2.08	1.95	3.21
Sept.	4.25	1.28	4.60	6.55	11.82	1.57	0.84	10.34	5.76	3.72
Oct.	2.27	1.60	2.22	3.41	0.86	1.93	2.78	3.93	1.24	2.43
Total	18.82	19.44	17.76	22.02	32.45	14.88	23.91	28.68	21.22	23.62

*Data taken from United States Meterological Station records at Madison, Wis.

RESULTS

YIELDS OF DRY MATTER AND CRUDE PROTEIN

The annual acre yields of dry matter and crude protein produced by the four fields during the period 1935 to 1942, inclusive, are given in Tables 2 and 3. These data show that the production of permanent pastures can be materially increased by nitrogen fertilization and by the use of alfalfa re-established periodically by renovation. There is

no indication that the type of rotational grazing practiced in field 3 was superior to continuous grazing under the conditions of the study.

TABLE 2.—*Yields of dry matter in pounds per acre of the four fields during the period 1935 to 1942, inclusive.*

Field No.	1935*	1936	1937	1938	1939	1940	1941	1942	Average
1.........	4,182	3,250	2,701	2,586	1,067	2,345	1,613	1,703	2,431
2.........	6,687	4,677	4,081	5,264	1,914	3,732	2,991	3,048	4,049
3.........	6,280	4,097	3,738	4,810	1,761	3,980	2,748	2,809	3,778
4.........	5,858	5,701	4,799	4,825	1,521	2,581	3,934	3,390	4,076
Average...	5,752	4,431	3,830	4,371	1,566	3,160	2,822	2,738	

*Early growth of forage was harvested as hay during the period July 6 to 19.

TABLE 3.—*Yields of crude protein in pounds per acre of the four fields during the period 1935 to 1942, inclusive.*

Field	1935	1936	1937	1938	1939	1940	1941	1942	Average
1.........	429	501	265	224	107	340	178	185	279
2.........	538	609	528	559	179	652	379	369	477
3.........	453	574	470	486	151	671	318	325	431
4.........	917	1,205	638	637	159	420	546	474	625
Average...	584	722	475	477	149	521	355	338	

The average annual acre yields in pounds of dry matter produced by fields 1 to 4, respectively, were 2,431, 4,049, 3,778, and 4,076. Field 2, which was continuously grazed and fertilized annually with calcium cyanamid, produced an average of 66.6% more forage per acre than field 1 which was continuously grazed but not fertilized with calcium cyanamid. Field 3, which was rotationally grazed and fertilized annually with calcium cyanamid, produced an average of 55.4% more forage per acre than field 1. The average acre yield of dry matter obtained from field 4, which was rotationally grazed and maintained in alfalfa and Kentucky bluegrass, was 67.7% greater than that of field 1.

The average annual acre yields of crude protein in pounds obtained from fields 1 to 4, respectively, were 279, 477, 431, and 625. The average increase in yield of crude protein as a result of annual applications of calcium cyanamid was 71.0% from field 2 and 54.5% from field 3. Likewise, field 4 produced an average of 124.0% more crude protein per acre annually than field 1.

It is apparent from Tables 2 and 3 that there was a marked tendency for the yields of dry matter and crude protein to decrease as the fields increased in age. Yields of dry matter and crude protein decreased even though rainfall conditions were less favorable early in the study than subsequently. The average acre yields of dry matter in pounds obtained from the four fields in 1935–36, 1937–38, 1939–40, and 1941–42 were 5,092, 4,101, 2,363, and 2,780, respectively. Likewise, the average acre yields of crude protein in pounds obtained

during the same periods were 653, 476, 335, and 347, respectively. These data show conclusively that yields of dry matter and crude protein were considerably lower during the last 4-year period of the study than during the first 4 years. The practice of maintaining permanent pastures for indefinite periods on non-erodable, productive crop land would appear to be open to question under conditions where results such as these are obtained.

The desirability and practicability of periodic cultivation and reseeding as a means of maintaining production at a maximum level is worthy of further study. The cause of the decline in production as the pastures increased in age is not clear. Decreases in yield which resulted may have been due in part to the depletion of the available phosphorus and potassium reserves of the soil. Data in Tables 4 and 5 suggest that decreases in yield may be associated in part with changes which occurred in the botanical composition of the sward of the fields. It is clear that Kentucky bluegrass had become the dominant species in the sward of fields 1, 2, and 3 by 1937 and in field 4 by 1938. Yields of forage produced by redtop and timothy occurring in fields 1, 2, and 3 decreased significantly each year during the period 1935 to 1939, inclusive. Yields of forage produced by redtop and timothy in field 4 were of no practical importance after 1936. Likewise, yields

TABLE 4.—*Yields of dry matter in pounds per acre produced by the species comprising the sward of fields 1, 2, and 3 during the period 1935 to 1941, inclusive.*

Year	Kentucky bluegrass			Redtop and timothy			Red, alsike, and white clover			Weeds		
	Field 1	Field 2	Field 3	Field 1	Field 2	Field 3	Field 1	Field 2	Field 3	Field 1	Field 2	Field 3
1935......	268	548	559	1,740	4,221	3,686	1,869	1,010	1,627	305	908	408
1936......	906	1,245	1,114	1,123	3,293	2,139	1,068	108	529	153	31	315
1937......	1,642	3,206	2,374	933	875	1,364	126	—	—	—	—	—
1938......	1,839	4,584	4,252	697	659	558	36	—	—	14	21	—
1939......	625	1,520	1,666	219	345	95	214	34	—	9	15	—
1940......	1,795	3,485	3,825	268	203	75	231	34	1	51	10	79
1941......	1,042	2,780	2,660	359	197	82	199	11	—	13	3	6

TABLE 5.—*Yields of dry matter in pounds per acre produced by species comprising the sward of field 4 during the period 1935 to 1941, inclusive.*

Year	Kentucky bluegrass	Redtop and timothy	Red, alsike, and white clover	Alfalfa	Weeds
1935	28	184	565	4,854	227
1936	382	536	108	4,658	17
1937	1,691	—	—	3,108	—
1938	3,450	48	—	1,327	—
1939	1,072	81	76	292	—
1940	1,843	10	—	710	18
1941	1,951	233	—	1,697	53

of forage produced by red clover, alsike clover, and white clover in all four fields were low after 1936. The alfalfa in field 4 provided considerable forage during most years and was maintained by renovation. Even with renovation, however, the stand of alfalfa in field 4 was markedly inferior to that obtained in the initial seeding. Yields of forage produced by Kentucky bluegrass increased each year in all of the fields during the period 1935 to 1938, inclusive. The data, however, indicate that the increases in yield which were obtained from Kentucky bluegrass during this period were not proportionate to the decreases in the yields of the other species.

There is no evidence that the grazing management which was accorded fields 1, 2, and 3 had any significant effect on the botanical composition. There is some indication, however, that plants of redtop, timothy, alsike clover, red clover, and white clover persisted in greater numbers in field 1 than in either field 2 or field 3.

The data given in Tables 2 and 3 show that calcium cyanamid was not equally effective in increasing yields of dry matter and crude protein in all years. Rainfall was below average during the growing period in 1935, 1936, 1937, 1939, and 1942. Likewise, rainfall was average or above in 1938, 1940, and 1941. The data indicate that calcium cyanamid was considerably less effective in increasing yields of dry matter and crude protein in years of deficient rainfall than in years of average or above average rainfall. During the period of deficient rainfall, the average annual acre yield of dry matter produced in fields 2 and 3 was 3,909 pounds, whereas that of field 1 was 2,581 pounds. Fields 2 and 3 thus produced an average of 51.5% more dry matter per acre than field 1 during this period. The average acre yield of dry matter produced by fields 2 and 3 during the period of average or above average rainfall was 3,921 pounds, whereas that of field 1 was 2,181 pounds. Fields 2 and 3 produced an average of 79.8% more forage per acre during this period than field 1.

During the period of deficient rainfall, the average annual acre yield of crude protein produced by fields 2 and 3 was 420 pounds, whereas that of field 1 was 297 pounds. Fields 2 and 3 produced an average of 41.4% more crude protein per acre during this period than field 1. The average annual acre yield of crude protein produced by fields 2 and 3 during the period of average or above average rainfall was 511 pounds, whereas that of field 1 was 247 pounds. Fields 2 and 3 produced an average of 106.9% more crude protein per acre during this period than field 1.

It is clear that differences in yields of dry matter and crude protein were generally small when comparisons are made between results obtained in years of deficient rainfall with those of years of average or above average rainfall. In field 1 average yields of dry matter and crude protein were actually lower during the years of average or above average rainfall than during the years of deficient rainfall. Such results may be due in part to the marked tendency for the yields to decrease as the fields increased in age even though rainfall was less favorable during the initial 4-year period than subsequently. Similar comparisons between the productivity of field 1 and field 4 cannot be made

inasmuch as grazing of various portions of field 4 was interrupted during the period of 1938 to 1940 to re-establish the alfalfa by renovation.

GRAZING DAYS

The production of pasture land is reflected in the number of animals carried per acre during the time it is grazed and in the actual number of days of grazing which are provided. Data relative to the periods during which the four fields were grazed and the number of grazing days provided per acre are given in Table 6 and in Fig. 1. Stocking was adjusted to the estimated carrying capacity of the different fields. The average number of cows carried per acre was 0.98, 1.28, 1.27, and 1.28 for fields 1 to 4, respectively, during the period 1935 to 1941, inclusive. The figures for the heifers used in 1938, 1939, and 1941 were converted to a cow basis by multiplying by the factor 0.625 or 0.75, according to the size and maturity of the animals.

TABLE 6.—*Number of pasture days per acre obtained from the four fields during the period 1935 to 1941, inclusive.*

Field No.	1935*	1936	1937	1938†	1939†	1940	1941‡	Average
1	43	81	70	142	65	82	84	81
2	44	107	111	266	104	160	150	135
3	42	107	129	273	120	165	157	142
4	53	131	98	257	78	86	178	126

*The early growth was harvested as hay during the period July 6 to 19.
†Heifers.
‡Cows and heifers.

Each of the four pastures was grazed for a period of 40 days in 1935 from August 15 to September 25. During the next 6 years, field 1 was grazed for an average of 76 days each year; field 2, 94 days; field 3, 100 days; and field 4, 93 days. The beginning and closing dates for each grazing period during each year are shown in Fig. 1. In all instances, except in field 4 in 1938 and 1941, it was necessary to remove the cattle from the fields to other supplementary pastures for varying intervals during the midsummer period when the grasses were dry and unproductive.

Fields 2, 3, and 4 were usually available for grazing from 5 to 7 days earlier in the spring than field 1. Likewise, fields 2, 3, and 4 usually provided grazing longer during the midsummer period than field 1. Field 4 was somewhat more effective in this respect than field 3. Similarly, field 3 provided grazing somewhat longer than field 2. The cattle were removed from field 4 each year during the period of September 15 to 25, even though additional forage was available for grazing, to safeguard the alfalfa plants against the hazards of winter. Since Kentucky bluegrass was the dominant vegetation in fields 1, 2, and 3, these fields could be grazed without injury later in the fall than field 4.

The average number of grazing days obtained per acre from fields 1 to 4, respectively, during the period 1935 to 1941, inclusive, were 81, 135, 142, and 126. Fields 2 and 3 provided an average of 66.7% and 75.3% more grazing days per acre, respectively, than field 1. The

average number of grazing days obtained from field 4 was 55.6% greater than that of field 1. Fields 2 and 3 provided an average of 9.9% more grazing days per acre during the period 1935 to 1941, inclusive, than field 4.

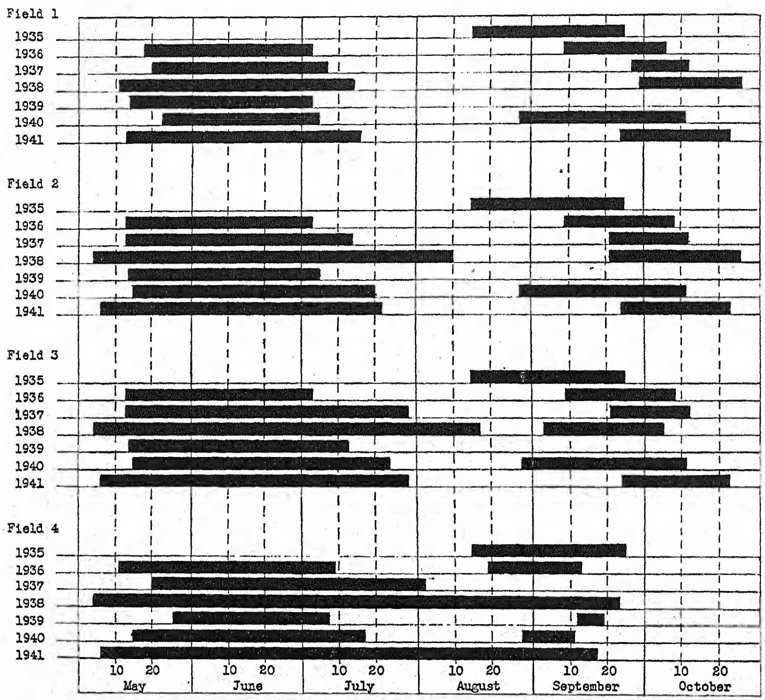


FIG. 1.—Seasonal grazing periods provided by the four fields during 1935 to 1941, inclusive.

TOTAL DIGESTIBLE NUTRIENTS

The amount of milk produced daily by each cow was determined and a composite sample was tested each week for percentage of butterfat. The formula suggested by Gaines and Davidson (4) was used to convert the milk production to a standard 4% fat-corrected basis. Total digestible nutrient requirements for maintenance and gains in live weight were calculated from the Morrison feeding standards (8). Values proposed by joint committees of the American Dairy Science Association, the American Society of Agronomy, and the American Society of Animal Production (11) were used in computing total digestible nutrients required for live weight increases and for allowances for live weight decreases. The total digestible nutrients produced by the pastures were determined by adding the total digestible nutrients required for maintenance, live weight increases, and milk production and deducting from this total the nutrients

allowed for live weight decreases and the nutrients provided in supplementary grain feeds. The yields of total digestible nutrients credited to the four pastures are given in Table 7.

TABLE 7.—*Total digestible nutrients in pounds per acre produced by the four fields during the period 1935 to 1941, inclusive.*

Year	Field 1	Field 2	Field 3	Field 4
1935	672	649	657	757
1936	1,306	1,806	1,734	1,655
1937	980	1,524	1,488	1,301
1938*	1,343	2,470	2,534	2,375
1939*	610	938	1,147	903
1940	1,037	1,480	1,471	624
1941†	981	1,804	1,716	1,920
Av. 1936–41, incl.	1,043	1,670	1,682	1,463

*Grazed by heifers.
†Grazed by cows and heifers.

The average yields of total digestible nutrients in pounds per acre obtained from fields 1 to 4, respectively, during the period 1936 to 1941, inclusive, were 1043, 1670, 1682, and 1463. Fields 2 and 3 provided an average of 60.1% and 61.3% more total digestible nutrients per acre, respectively, than field 1. The average acre yield of total digestible nutrients provided by field 4 was 40.3% greater than that of field 1. Fields 2 and 3 provided an average of 14.6% more total digestible nutrients per acre during the period 1936 to 1941, inclusive, than field 4.

DISCUSSION OF RESULTS

The data indicate that field 1 was less productive than any of the other fields on the basis of all methods of evaluation used. There was no difference of practical importance in the production of field 2 which was continuously grazed and field 3 which was rotationally grazed. Field 3 provided a few more pasture days per acre than field 2 during 5 of the 7 years of the study. Field 3 provided an average of 7 pasture days per acre more than field 2 during the period 1935 to 1941, inclusive, and only 12 pounds more total digestible nutrients per acre during the same period. On the other hand, yields of dry matter produced in field 2 were somewhat greater than those obtained from field 3 during 7 of the 8 years of the study. Field 2 provided an average of 271 pounds, or 7.2%, more dry matter per acre than field 3 during the period 1935 to 1942, inclusive. It is clear from these results that differences in the production of fields 2 and 3 were small and of doubtful practical significance.

Hodgson, Grunder, Knott, and Ellington (7) report the same number of cow pasture days per acre from rotationally and continuously grazed pastures and an increase of 8.82% in total digestible nutrients in favor of rotational grazing. They have concluded that it is doubtful if increases in yields of nutrients obtained by producing cows from rotational grazing alone would justify the added costs involved.

Hein and Cook (6) found no significant difference in average gains made by steers on continuously and rotationally grazed pastures.

Woodward, Shepherd, and Hein (13) have reported that yields of total digestible nutrients obtained under a system of rotational grazing were 10.4% greater than those of continuously grazed areas and that rotational grazing and heavy fertilization increased the yield 28.6%.

Comfort and Brown (3) found that the average yield of beef in pounds per acre from a continuously grazed pasture was 112 and that of a rotationally grazed pasture was 97. The failure to obtain any appreciable advantage from rotational grazing under Wisconsin conditions may be due, in part, to actual differences between the fields in which the comparisons were made. Field 3 was somewhat more unfavorably situated with respect to available soil moisture than field 2. The effect of the grazing managements which were used in these two fields may have been masked by differences in the available moisture content of the soil. It is also entirely possible that a more intensive system of management than that used in these studies, in which dry stock and heifers would follow milking cows in grazing the pasture and in which excess forage produced in years of abundant rainfall is preserved either as hay or silage, would result in greater advantages under a system where rotational grazing is practiced.

The production of field 4 was lower than that of fields 2 and 3 when evaluated in terms of grazing days and total digestible nutrients. Fields 2 and 3 produced an average of 1,670 and 1,682 pounds of total digestible nutrients per acre, respectively, during the period 1936 to 1941, inclusive, whereas field 4 produced an average of 1,463 pounds of total digestible nutrients per acre during the same period. Fields 2 and 3 produced an average of 14.6% more total digestible nutrients per acre during the period 1936 to 1941, inclusive, than field 4. Fields 2 and 3 provided an average of 135 and 142 grazing days per acre, respectively, during the period 1935 to 1941, inclusive, whereas field 4 provided an average of 126 grazing days per acre during the same period. Fields 2 and 3 thus provided an average of 9.9% more grazing days per acre during the period 1935 to 1941, inclusive, than field 4.

The production of fields 2, 3, and 4 did not differ significantly when evaluated in terms of yield of dry matter per acre. The yields of dry matter obtained from field 4 were greater than those of fields 2 and 3 in 4 of the 8 years and lower than those of fields 2 and 3 in 3 of the 8 years. Differences in results obtained in fields 2, 3, and 4 when based on dry matter determinations, on the one hand, and total digestible nutrients and grazing days, on the other, may be due in part to sampling error. Alfalfa was generally more succulent than Kentucky bluegrass during most of the growing period. There was a tendency for the alfalfa to be trampled and for the erect growing stems to be broken over in grazing to a greater extent than in the Kentucky bluegrass. It may not have been possible to sample this field by the procedure used with the same degree of accuracy as was achieved in the other fields where the amount of forage remaining at the completion of the grazing period was more readily apparent. Data in Table 5 indicate

that alfalfa was the dominant vegetation in field 4 prior to 1938. The greatest discrepancies between yields of dry matter, on the one hand, and total digestible nutrients and grazing days, on the other, occurred prior to 1938. It is undoubtedly true, however, that results obtained from fields 2, 3, and 4 would be more comparable if all methods of evaluation were based on data obtained during the 8-year period of the study. Data relative to total digestible nutrients and grazing days are based on results obtained during 6 and 7 years, respectively, whereas those for yields of dry matter and crude protein are based on results obtained during 8 years. Very little forage was available for grazing in those portions of field 4 which were renovated during the period 1938 to 1940, inclusive. Results, however, during this period as in all other years are reported on a per acre basis for the entire area. Grazing lost in the renovation of this field during the period 1938 to 1940, inclusive, is averaged against 6 years of results in computing acre yields of total digestible nutrients, 7 years of results in computing grazing days, and 8 years of results in computing yields of dry matter and crude protein.

Fields 2 and 3 produced an average of 633 pounds more total digestible nutrients per acre each year during the period 1936 to 1941, inclusive, than field 1. The average annual cost of the calcium cyanamid applied to fields 2 and 3 was $5.25 per acre. The increased yields of total digestible nutrients from fields 2 and 3 as a result of nitrogen fertilization were obtained at a cost of 83 cents per 100 pounds. The 633 pounds of total digestible nutrients are equivalent to 1,258 pounds of alfalfa hay and were produced at a fertilizer cost of $8.35 per ton of hay.

Field 4 produced an average of 420 pounds of total digestible nutrients per acre more each year during the period 1936 to 1941, inclusive, than field 1. Various portions of this field were renovated with alfalfa during the period 1938 to 1940, inclusive, at an estimated cost of $11.40 per acre. Cost of fertilizer (muriate of potash), seed, and preparation of the seedbed were included in arriving at an estimation of the cost of renovation. If it is assumed that the beneficial effects of renovation are apparent for 6 years following such treatment, the increased production of total digestible nutrients obtained from this field was obtained at a cost of $1.90 per acre per year. On this basis the increased yields of total digestible nutrients from field 4 as a result of renovation were obtained at a cost of 45 cents per 100 pounds. The 420 pounds of total digestible nutrients are equivalent to 835 pounds of alfalfa hay and were produced at a cost of $4.55 per ton of hay.

SUMMARY

Comparisons of the production of permanent pastures which were (a) continuously grazed (field 1), (b) continuously grazed and fertilized annually with calcium cyanamid (field 2), (c) rotationally grazed and fertilized annually with calcium cyanamid (field 3), and (d) rotationally grazed and maintained in alfalfa and Kentucky bluegrass (field 4) were made during the period 1935 to 1942, inclusive.

Evaluations of the fields based on (a) yields of dry matter and crude protein, (b) grazing days, and (c) yields of total digestible nutrients

indicate that the production of permanent pastures can be materially and profitably increased by nitrogen fertilization and through the use of alfalfa re-established periodically by renovation.

There was a marked tendency for yields of dry matter and crude protein to decrease as the pastures increased in age even though calcium cyanamid was applied annually in fields 2 and 3 and alfalfa was maintained in field 4 by renovation. Yields of dry matter and crude protein were generally considerably lower during the last 4-year period of the study than during the first 4-year period. Maintaining permanent pastures for indefinite periods on productive, non-erodable crop land would not appear justified on the basis of the results obtained in these trials, provided maximum productivity is desired. If maximum yields of forage are desired, occasional plowing (productive, non-erodable soils) or renovation (unproductive, erodable soils) followed by adequate fertilization and the re-establishment of grass and legume species may be necessary in humid areas where white clover or other legumes are not readily maintained.

Fields 2, 3, and 4 were more productive than field 1 on the basis of all methods of evaluation used in the study. There were no significant differences in the production of field 2 which was continuously grazed and field 3 which was rotationally grazed. The average annual production of fields 2 and 3 was 9.9% and 14.6% greater on the basis of grazing days and total digestible nutrients provided per acre, respectively, than that of field 4. Yields of dry matter produced by fields 2, 3, and 4 did not differ significantly. Increased acre yields of total digestible nutrients were produced at an average cost of 83 cents per 100 pounds in fields 2 and 3 and 45 cents per 100 pounds in field 4.

Calcium cyanamid was less effective in increasing yields of dry matter and crude protein in years of below average rainfall than in years of average or above average rainfall.

Fields 2, 3, and 4 were usually available for grazing from 5 to 7 days earlier in the spring and for a longer period in midsummer than field 1.

Yields of forage produced by redtop and timothy in fields 1, 2, and 3 decreased each year during the period 1935 to 1939. Yields of forage produced by redtop and timothy in field 4 were of no practical importance after 1936. Yields of forage produced by red clover, alsike clover, and white clover were very low in all fields after 1937. Kentucky bluegrass had become the dominant species in the sward of fields 1, 2, and 3 by 1937 and in the sward of field 4 by 1938. Yields of forage produced by Kentucky bluegrass increased each year in all fields during the period 1935 to 1938, inclusive. The increases in yield which were obtained from Kentucky bluegrass during this period were not proportionate to the decreases in the yields of the other species.

The botanical composition of the sward of field 2, which was continuously grazed, and field 3, which was rotationally grazed, did not differ significantly. Plants of redtop, timothy, alsike clover, red clover, and white clover persisted in greater numbers in field 1, which was

not fertilized with calcium cyanamid, than in either field 2 or field 3, both of which were fertilized annually with calcium cyanamid.

LITERATURE CITED

1. A. O. A. C. Methods of Analysis. Washington, D. C. Ed. 4, 1935.
2. CARDON, P. V. Toward a grassland agriculture. Jour. Amer. Soc. Agron., 31:229–231. 1939.
3. COMFORT, J. E., and BROWN, E. M. Systems of pasture utilization. Amer. Soc. An. Prod. Proc., 26:74–77. 1934.
4. GAINES, W. L., and DAVIDSON, F. A. Relation between percentage fat content and yield of milk. Ill. Agr. Exp. Sta. Bul. 245. 1923.
5. GRABER, L. F. Renovating bluegrass pastures. Wis. Agr. Exp. Sta. Circ. 277, 1936.
6. HEIN, M. A., and COOK, A. C. Effect of method and rate of grazing on beef production and plant population of pastures at pastures at Beltsville, Md. U. S. D. A. Tech. Bul. 538. 1937.
7. HODGSON, R. E., GRUNDER, M. S., KNOTT, J. C., and ELLINGTON, E. V. A comparison of rotational and continuous grazing of pastures in western Washington. Wash. Agr. Exp. Sta. Bul. 294. 1934.
8. MORRISON, F. B. Feeds and Feeding. Ithaca, N. Y.: The Morrison Company. Ed. 20. 1936.
9. PIETERS, A. J. A digest of pasture research literature in the continental United States and Canada, 1855 to 1935. Bur. Plant Ind., U.S.D.A. 1936.
10. ————. A digest of some world pasture research literature (exclusive of the continental United States and Canada). Bur. Plant Ind., U.S.D.A. 1938.
11. Report of joint committee of A.S.A., A.D.S.A. and A.S.A.P. Preliminary report on pasture investigation techniques. Jour. Dairy Sci., 26:353–369. 1943.
12. WHITE, J. W. Comparative returns in feed units from crop rotation and pasture. Jour. Amer. Soc. Agron., 21:589–593. 1929.
13. WOODWARD, T. E., SHEPHERD, J. B., and HEIN, M. A. The Hohenheim system in the management of permanent pastures for dairy cattle. U.S.D.A. Tech. Bul. 660. 1938.

WHAT IT TAKES TO TEACH THE PLANT SCIENCES[1]

NEIL E. STEVENS[2]

"A NAIVE approach to a problem", it is said "often insures its solution". At least, such an approach often yields interesting results. In trying to get some light on the usefulness of "rating scales" as an aid in evaluating teaching, what could be more natural—naive, if you like—than to get "ratings" of some of the teachers recognized as great by their mature students? With this—and perhaps other ends—in view, a rating scale for teachers was mailed to some 1,700 professional workers in the plant sciences, members of the Botanical Society of America or the American Society of Agronomy. They were requested to rate, as objectively as possible, the teachers who had most influenced them in the field of plant science, or seemed the most influential in their undergraduate or graduate careers.

The response was generous. It included over 1,100 ratings of more than 400 individual teachers, together with a small avalanche of letters. Incidentally, this indicates a very general interest in teaching and its problems.

The composition of the Botanical Society of America was analyzed by Tippo in 1940.[3] According to him, approximately one-half of the total "interests" of the society lie in the morphological field in which he included systematic botany, cytology, etc., a little less than a fourth in physiology, and less than 10% each in pathology, ecology, and genetics. It thus overwhelmingly represents pure science, if there is any such thing. The American Society of Agronomy, on the other hand, must represent in large measure students of plant science who are conscious of its important practical possibilities.

The rating scale was chosen largely on the basis of availability.[4] It is in a form now familiar, giving opportunity to evaluate, on a scale of 1 to 100, the following 10 characteristics arranged in the order named: Interest in subject, sympathetic attitude toward students, fairness in grading, liberal and progressive attitude, presentation of subject matter, sense of proportion and humor, self-reliance and confidence, personal pecularities, personal appearance, stimulating intellectual curiosity. In interpreting the results, the writer has had the assistance of several people, particularly Dr. I. A. Berg and Dr. E. L. Welker of the faculty of the University of Illinois.

The very wide distribution of the answers is significant and was surprising. The highest number of returns for any one teacher was 22. This seems to indicate that the active botanists of this generation in the United States have derived their inspiration from widely scattered sources. No one man—or group of men—can have dominated American botanical teaching to the extent that may appear on the surface.

---

[1]Contribution from the Department of Botany, University of Illinois, Urbana, Ill. Received for publication October 7, 1943.

[2]Professor.

[3]TIPPO, OSWALD. An analysis of the major interests of the members of the Botanical Society of America. Science, 94:326–327. 1940.

[4]BRANDENBURG, G. C., and REMMERS, H. H. The Purdue Rating Scale for Instructors. Lafayette, Ind.: Lafayette Printing Co.

Over and over again professional botanists pointed out as their most influential and effective teacher some man who is himself quite unknown in the field. Perhaps a single example will be permitted. W. C. Coker and W. W. Garner would surely stand high in any list of those who have contributed to the advancement of plant science in this generation. Yet both write in the highest terms of the botanical instruction given by Dr. James Woodrow, professor (later president) of the University of South Carolina. Dr. Woodrow, was the uncle of Woodrow Wilson—himself a great teacher. He was evidently an unusual teacher, but he is certainly not remembered as a botanist.

Although the number of agronomists reached was much smaller than the number of botanists, the same wide distribution is shown. Over 80 individual teachers were rated by the agronomists who included on the rating sheet the name of the person rated. All the rating sheets with no name are included under "anonymous". It should be borne in mind that the classification is based on the present occupation of the person who marked the rating scale. Thus, "named agronomists" as used in the text and figures is merely an abbreviation for "teachers of plant science rated by some one who is now professionally employed in the field of agronomy." A few teachers were rated in both groups.

The information given on the rating scales themselves is summarized in Figs. 1, 2, and 3 in which the characteristics are arranged as they were in the rating sheet. Table 1 gives the same information but with the various characteristics arranged in descending order of the scores of the named botanists. The curves are obviously similar. They seem to indicate that regardless of the field in which they now work, students of the plant sciences have about the same ideas as to the qualities of their teachers. In general, the agronomists were somewhat more severe in their judgments and within this group those who did not name their teachers were even more severe.

TABLE 1.—*Averages of all returns on rating scale for teachers of plant science.*

Characteristics	Botanists		Agronomists	
	Named (725)	Anonymous (131)	Named (112)	Anonymous (108)
Interest in subject	90.3	90.4	90.0	84.6
Stimulating intellectual curiosity	88.5	88.3	87.8	83.8
Self-reliance and confidence	85.9	84.1	85.5	82.7
Presentation of subject matter	83.4	83.0	84.5	81.6
Sympathetic attitude toward students	83.3	83.0	80.7	78.2
Fairness in grading	83.2	80.9	87.3	80.7
Personal appearance	82.6	80.0	81.7	76.0
Sense of proportion and humor	78.7	78.0	76.2	72.2
Liberal and progressive attitude	78.5	74.8	79.0	75.0
Personal peculiarities	78.4	75.3	79.1	73.5

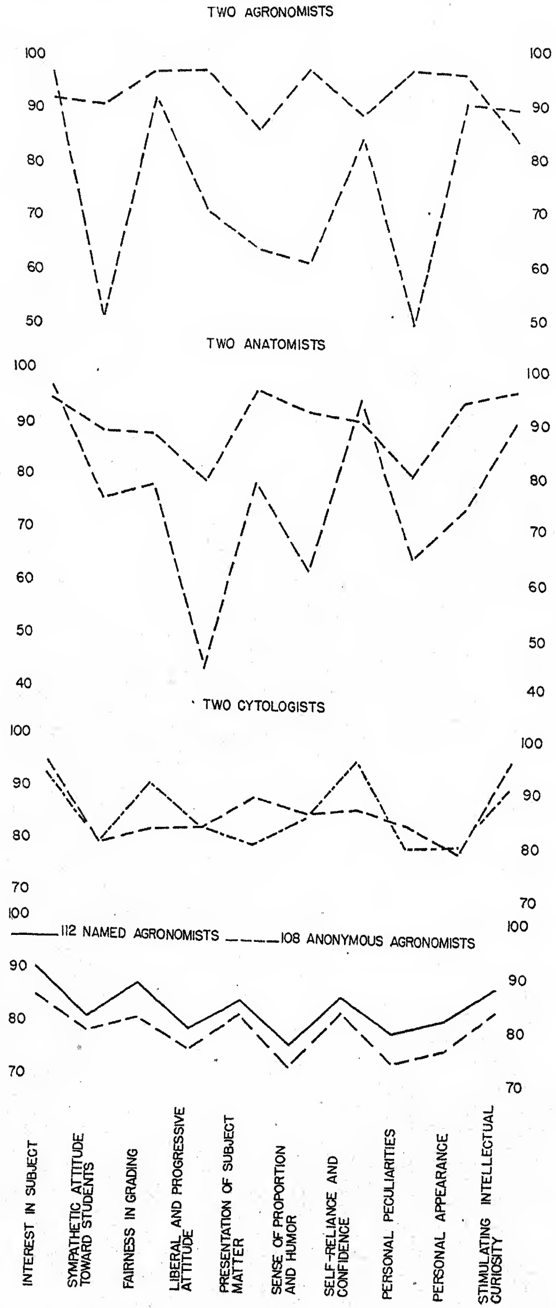

TWO AGRONOMISTS
TWO ANATOMISTS
TWO CYTOLOGISTS
112 NAMED AGRONOMISTS
108 ANONYMOUS AGRONOMISTS
INTEREST IN SUBJECT
SYMPATHETIC ATTITUDE TOWARD STUDENTS
FAIRNESS IN GRADING
LIBERAL AND PROGRESSIVE ATTITUDE
PRESENTATION OF SUBJECT MATTER
SENSE OF PROPORTION AND HUMOR
SELF-RELIANCE AND CONFIDENCE
PERSONAL PECULIARITIES
PERSONAL APPEARANCE
STIMULATING INTELLECTUAL CURIOSITY

FIG. 1.

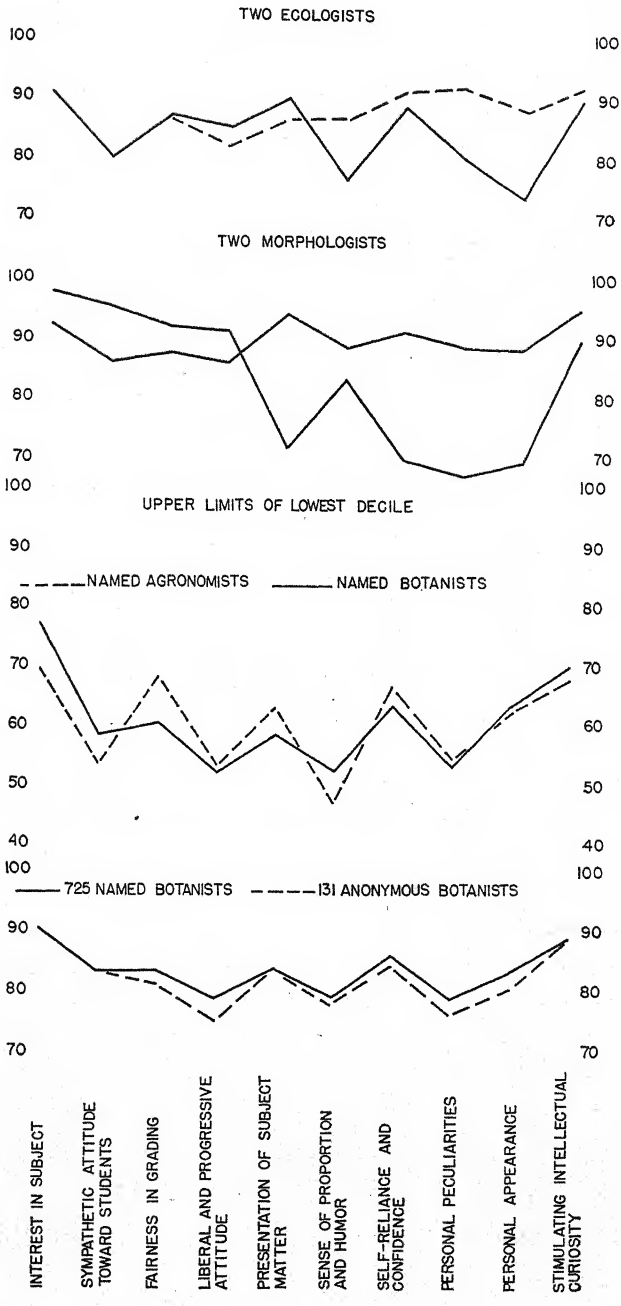
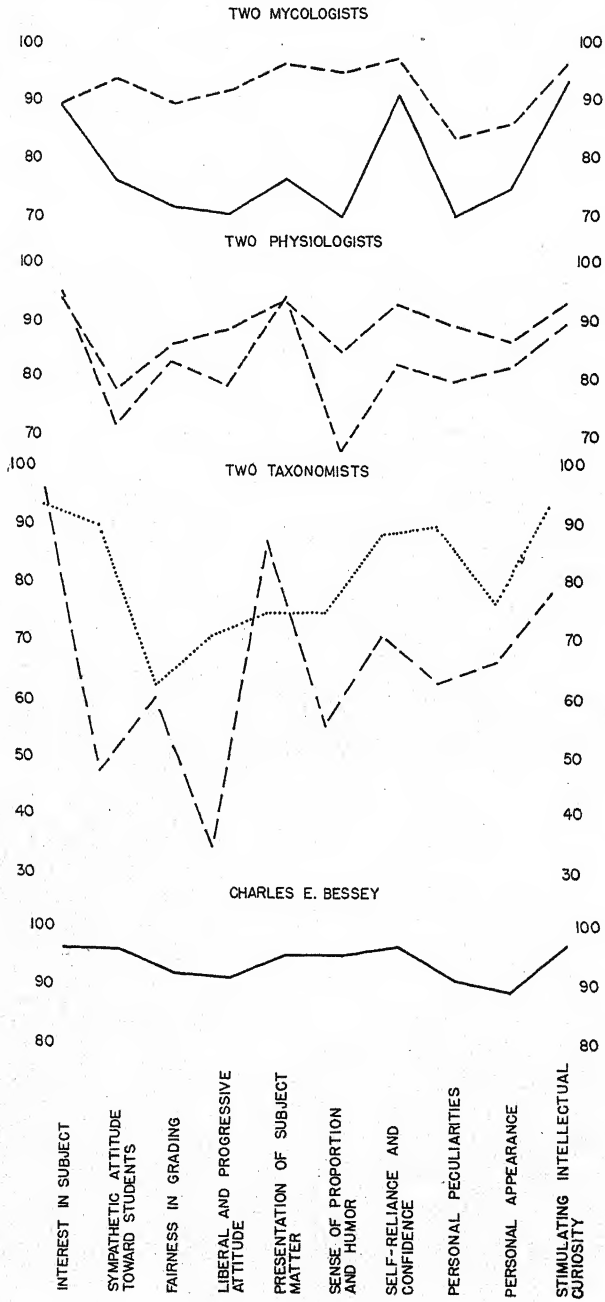

TWO ECOLOGISTS
TWO MORPHOLOGISTS
UPPER LIMITS OF LOWEST DECILE
NAMED AGRONOMISTS
NAMED BOTANISTS
725 NAMED BOTANISTS
131 ANONYMOUS BOTANISTS
100
90
80
70
60
50
40
INTEREST IN SUBJECT
SYMPATHETIC ATTITUDE TOWARD STUDENTS
FAIRNESS IN GRADING
LIBERAL AND PROGRESSIVE ATTITUDE
PRESENTATION OF SUBJECT MATTER
SENSE OF PROPORTION AND HUMOR
SELF-RELIANCE AND CONFIDENCE
PERSONAL PECULIARITIES
PERSONAL APPEARANCE
STIMULATING INTELLECTUAL CURIOSITY

FIG. 2.



TWO MYCOLOGISTS
100
90
80
70
TWO PHYSIOLOGISTS
100
90
80
70
TWO TAXONOMISTS
100
90
80
70
60
50
40
30
CHARLES E. BESSEY
100
90
80
INTEREST IN SUBJECT
SYMPATHETIC ATTITUDE TOWARD STUDENTS
FAIRNESS IN GRADING
LIBERAL AND PROGRESSIVE ATTITUDE
PRESENTATION OF SUBJECT MATTER
SENSE OF PROPORTION AND HUMOR
SELF-RELIANCE AND CONFIDENCE
PERSONAL PECULIARITIES
PERSONAL APPEARANCE
STIMULATING INTELLECTUAL CURIOSITY

FIG. 3.

In view of the unusual nature of the present inquiry it may be desirable to point out specifically its object and limitations. It is not concerned with what constitutes a theoretically ideal teacher or even directly with the improvement of teaching. The purpose was to determine what, in fact, were the characteristics of the most successful teachers of plant science, as expressed in the judgement of those former students who are still active in that field.

The values given in the charts and in Table 1 are averages of all the returns. The well recognized limitations of averages as means of expressing the significance of rather widely varying figures made it seem desirable to attempt some analysis. In figures which by the nature of the inquiry must be predominantly at one end of the curve, standard deviations would almost certainly give a false impression. It seemed possible that a better appraisal would be made possible by curves showing the upper limits of the lowest decile. These are given for the named teachers (Fig. 2). They show that 10% of both groups rated their best teachers of plant science below 60 in sympathetic attitude toward students, liberal and progressive attitude, sense of proportion and humor, and personal peculiarities. In the last three named the ratings were below 55.

The values here given are of course the averages of the returns on the rating scales themselves. If the figures are converted into Purdue percentile equivalents, the range of the figures is of course greatly increased and in the five characteristics at the bottom of the list these leading teachers of plant science fall in some rather low percentiles. However, in all the categories in Table 1, the same four characteristics remain at the top, the chief, and in the largest group the only difference, being that "Stimulating Intellectual Curiosity" comes first instead of second.

All curves reach their highest point in "interest in subject". Second is "stimulating intellectual curiosity". "Self confidence" makes a natural third. Next comes a group of characteristics some of which at least might be considered as of particular importance in teaching, notably "presentation of subject", "sympathetic attitude toward students", and "fairness in grading". The last and lowest group is composed of three characteristics which seem to relate more particularly to teachers of plant sciences as human beings. A member of the profession can hardly be expected to enjoy such relatively low ratings in "sense of proportion and humor" and in "liberal and progressive attitude". Some consolation, however, may be found in the fact that Bradenburg and Remmers[5] (p. 21–22) reported 15 years ago in a study of the same scale as used among under-graduates that there seemed to be a negative correlation between interest in subject matter and sense of proportion and humour.

All groups agree on one point, that the teachers who seemed to them most influential and most successful were vitally interested in the subject they taught. Given this, they might seem unsympathetic toward students, grade too severely or with favoritism, be conspicuously lacking in sense of proportion and humour, appear illiberal or

[5] *Loc. cit.*, pages 21–22.

unprogressive, and yet succeed as teachers. It may be that here lies one of the reasons that our so-called general science courses are kept alive with so much difficulty. A man may well have a consuming interest in the taxonomy of Bidens, or the morphology of grass seeds, but he can hardly long maintain an interest in generalities, no matter how glittering.

No reader of this JOURNAL could be so inept as to assume that the averages in Table 1 are regarded as *directly* expressing the opinion of professional students of plant science as to the relative importance in teaching of the various characteristics named in the Purdue Rating Scale. The mere fact, however, that by all the groups certain characteristics were rated much lower than others seems to indicate that they were less important. Judged by this evidence personal peculiarities, including appearance, together with a sense of humor and a liberal attitude, seem of least importance. Those elements which have to do with teaching as teaching occupy at best but an intermediate place. The essential qualities in these teachers of plant science seem to have been a consuming interest in the subject, real ability to awaken that interest in others, and the degree of self confidence such enthusiasm must engender.

The assumption made in the foregoing paragraph is merely that the qualities actually observed to be outstanding in over 400 widely scattered successful teachers of a subject might well be those most important in teaching that subject. It is only fair to admit that the validity of this assumption is questioned by no less an authority than the genial junior author of the Purdue Rating Scale. It may be pointed out, however, that the four characteristics which rank highest in Table 1 are also the four highest in his own rating based on student judgements.[6] The only real difference here is that the students placed "Presentation of Subject Matter" first while it is fourth in Table 1. Argument in such a matter is worse than useless, but the question may perhaps be fairly raised as to whether in a natural problem area the actual method of presentation of subject matter is as important as it is often believed to be.

As judgements on teaching merely as teaching, the opinions expressed may be criticized on the ground that they were made by men who are themselves specialists. We are not concerned here, however, with teaching *in vacuo*, but with the teaching of the plant sciences to those who actually learned something about them. On this professional workers in the field should be competent judges. How well the opinions of the group actually reached represent those of the great mass of good students who also learned something about plants but are not now professionally concerned with them must be left to the judgement of the reader. The opinions of those students who flunked their first course, in whom no interest was ever aroused, who were too stupid to understand even the simple generalizations of beginning courses, or too lazy to master the needed additions to their vocabularies are not here represented. The study of the reactions of these groups must be left to those who are professionally concerned with this type of student.

[6]STALNAKER, J. M., and REMMERS, H. H. Can students discriminate traits associated with success in teaching? Jour. Appl. Psychology, 12:602–610. 1928.

The results seem to indicate that for the type of student reached enthusiasm for a subject has often carried a teacher to success in spite of remembered lacks in other respects. There seems to be no evidence that exceptional technical skill has compensated for the lack of this quality.

RATINGS OF INDIVIDUAL TEACHERS

The points mentioned above are even more strikingly evidenced in the curves derived from averaging the scores received from various individual teachers. These are in no way "selected". They merely represent the teachers most often rated in each field.

In view of the fact that we specifically asked for rating of teachers who had been particularly influential and to the further fact that the ratings were often based on recollections of 10 to 50 years earlier, it seemed possible that the "halo effect" might largely destroy the validity of the answers. As is well known this effect is the result of the lack of ability to discriminate among the traits of a given individual. The rater tends to judge the person in general terms, as very good or very poor. Actually this seems not to have been the case in this study. It is evident that in scoring most of the sheets each person had in mind a very definite picture of a specific teacher. This is emphasized by the letters which accompanied many of the rating sheets. These letters should eventually form the basis of a series of short notes on how the great figures in American botany taught. Such a series might well serve to illustrate the futility of discussions as to the relative efficiency of lecture vs. laboratory or other methods of instruction.

All will admit that C. E. Bessey and J. M. Coulter were great teachers of botany. To compare them would be as futile as to compare Christy Mathewson and Walter Johnson. Yet Coulter, I am told, rarely went into the laboratory and Bessey did his best teaching there. Who shall chose? "By their fruits ye shall know them." Botanists at least know that fruit of excellent flavor, proved nutritive value, and high vitamin content may be produced on trees of different genera.

Without such explanatory sketches it would be unfair to give the names of men whose individual scores appear in the charts. An exception is made in the case of Charles E. Bessey (Fig. 3) who seems to be, almost literally, in a class by himself. Many of the others will be readily guessed by their colleagues, particularly with the explanation that all of those whose scores are indicated by dotted lines were living on August 15, 1943. For the present they may serve to illustrate how divergent have been the personalities that have contributed to the advancement of plant science in America by teaching those who are today active in the field. Different, however, as those personalities were they had one common characteristic. No matter how low the curves may dip at some point they are high in "interest in subject" and in the ability to arouse that interest in others. These a teacher in our field must have. Teaching may be a little like love making. If the available literature is to be believed, many technics have been successful in this field, but there appears to be no written record of a successful lover who was not interested in his subject.

DETERMINATION OF SOIL DROUGHT RESISTANCE IN GRASS SEEDLINGS[1]

DEAN F. MCALISTER[2]

A LOW available water supply is the chief limiting factor in the establishment and maintenance of stands of perennial grasses in many parts of the western United States. If a plant is to survive under conditions of limited water supply, it must either possess some degree of drought resistance, i.e., ability to withstand permanent wilting without serious injury; be able to escape drought by completing its life cycle before drought sets in, as in winter annuals and desert ephemerals; or possess morphological adaptations which make it efficient in the absorption and/or use of a limited water supply. Well-established plants of native and introduced grass species that are adapted to arid conditions are usually capable of withstanding to some extent even severe and prolonged droughts. Death to seedlings, however, may result from minor droughts which may cause only a temporary loss of growth to mature plants. Schultz and Hayes (15),[3] Mueller and Weaver (10), and Glendening (5) have all stressed the fact that the seedling year is the critical period in the life-cycle of perennial grasses so far as drought is concerned.

There is a need for studies of factors affecting the establishment and development of various grass species in view of the large amount of natural or artificial reseeding which must be accomplished to restore grass lands depleted by drought, improper management, and erosion. A quantitative method for determining drought resistance of grasses under controlled environmental conditions to supplement field tests may aid in selection of suitable native and introduced species for current range reseeding programs, as well as in the testing of new strains being developed for areas affected by drought. This paper presents a direct technic for determining soil drought resistance of grass seedlings under controlled conditions and gives the results of some preliminary trials.

REVIEW OF LITERATURE

Many attempts have been made to measure the drought resistance of plants artificially. These studies may be divided into two groups, first, the indirect determinations of morphological, physiological, or physico-chemical phenomena

[1]Contribution from the Division of Forage Crops and Diseases, Bureau of Plant Industry, Soils, and Agricultural Engineering, Agricultural Research Administration, U. S. Dept. of Agriculture, in cooperation with the Utah Agricultural Experiment Station and the Intermountain Forest and Range Experiment Station, U. S. Forest Service, Logan, Utah. Received for publication November 8, 1943.

[2]Assistant Physiologist, U. S. Dept. of Agriculture. Seeds of the species and strains of grasses used in these studies were obtained through the courtesy of M. A. Hein, Wesley Keller, L. C. Newell, and H. H. Rampton, of the Division of Forage Crops and Diseases, Bureau of Plant Industry, Soils, and Agricultural Engineering, Agricultural Research Administration, U. S. Dept. of Agriculture, and D. C. Smith, formerly with the Department.

[3]Figures in parenthesis refer to "Literature Cited", p. 335.

known to be associated with drought resistance; and second, the direct measurements of the effects of controlled soil or atmospheric drought on living plants. Recent investigations have failed to show a satisfactory correlation between the factors considered in the indirect approaches in measuring drought resistance. Haber (6) was unable to classify inbred lines of sweet corn on the basis of their morphological or physiological characteristics, although the characters studied are thought to influence the resistance of plants to drought. Newton and Martin (12) found a direct relationship between bound water and drought resistance in the grasses studied, while the results of Whitman (19) and Carroll (3) failed to show a close association between these phenomena. Whitman found instead that the bound water content of the grasses studied was an expression of the aridity of their environment rather than of their ability to withstand drought.

Direct methods of determining drought resistance, in which the reaction of plants to a controlled drought treatment is observed, have proved successful. The Russian investigations, chiefly those of Maximov (9) and his co-workers, have been reviewed by Aamodt and Johnston (2). Shirley (16) developed a technic and apparatus for the determination of drought resistance in conifer seedlings in which potted plants were exposed to a drought treatment under uniform conditions of light, temperature, humidity, and wind velocity. Pine seedlings reacted to this controlled test (17) in a manner closely similar to their behavior under conditions of field drought. A machine for producing atmospheric drought conditions was developed by Aamodt (1) and successfully used (2) for the evaluation of spring wheat varieties for this type of drought.

Hunter, Laude, and Brunson (7) described a method for determining relative heat and drought tolerance between inbred lines of field corn in which seedlings were subjected to high temperature and low humidity. A good correlation was shown between seedling injury produced under controlled conditions and that observed in the same inbred lines in the field. Haber (6), using a similar procedure, was able to differentiate between inbred lines of sweet corn as to their drought resistance. Saks (14), after experience with direct methods of evaluating wheat varieties for drought resistance, came to the conclusion that the most satisfactory test is one in which plants are exposed to drought under controlled environmental conditions.

Schultz and Hayes (15) tested 14 species of grasses, 4 clovers, and alfalfa for their reaction to drought in Shirley's (16) drought machine. The plants were treated as 30- and 60-day-old seedlings and as sod material grown in 4-inch pots. The treatment was essentially one of atmospheric drought in which the plants were exposed to air moving at a velocity of 5 miles per hour, held at a temperature of 43° C and a relative humidity of 17% for periods of 10, 16, and 20 hours. The 16-hour treatment was most effective in differentiating between the species and strains tested. The amount of injury was found to be proportional to the relative drought resistance of the plants under field conditions.

The soil and atmospheric drought resistance of seedlings of 14 prairie grass species have been studied by Mueller and Weaver (10). These experiments were carried out under greenhouse conditions, the soil drought being effected by withholding water from the plants. Atmospheric drought was attained by passing a current of air heated to a temperature of 110° to 145° F over the seedlings for varying lengths of time. The short prairie grasses, blue grama, hairy grama, and buffalo grass, seemed to have the greatest soil drought resistance. While the results from the atmospheric tests were not so clear cut, the short, or upland, grasses were more resistant to hot dry wind than the tall prairie grasses.

Carroll (3) found, in a study of the effects of high and low nitrogen on the reaction of 15 turf grasses to several environmental factors, that heavy nitrogen fertilization decreased the resistance of the plants to soil drought and to high and low temperatures. The grasses were tested as potted sod plugs under greenhouse conditions. Soil drought was obtained by exposing the plants to a temperature of 35° C for 4 hours each day and withholding water until the soil in which they were growing was below the wilting coefficient. The reactions of the species tested for soil drought under greenhouse conditions agreed with field observations.

MATERIALS AND METHODS

A standard procedure was developed for testing grass seedlings to soil drought. Plants were grown in galvanized iron flats having dimensions of 14×19×3½ inches, in which 450 newsprint bands, ¾ inches square and 3¼ inches deep, were placed to serve as individual containers for the seedlings. Each flat contained 18 rows of 25 bands that were filled with a sandy-loam soil to which a complete fertilizer (Vigoro) was added at the rate of 100 grams to each 5 gallons of air-dry soil. An equal amount of soil was added to each of five flats used in an experiment, each flat representing one replication. The 16 inner rows of bands were planted to 16 strains or species, their positions within the flat being at random. The two outer rows were planted to one of the 16 strains to serve as buffers. Seeds were germinated on the surface of moist soil and a single seed transferred to each band with forceps before the sprouts were ½ inch in length. This procedure usually resulted in a nearly complete stand of seedlings in the bands. Perfect stands were obtained about a week later by replacing missing plants with seedlings from the germinator trays. A more complete description of the procedure for growing seedlings in ¾-inch newsprint bands has been published by the writer (8).

Subsequent growth of the grass seedlings was favored by optimum moisture, temperature, and light (long day) conditions in the greenhouse for a period of 6 weeks to 2 months before the drought treatment was applied. At the time of the drought the plants were usually from 9 to 18 inches in height and had two to six tillers, depending upon the species.

For the drought treatment the plants were placed in a chamber constructed to insure uniform environmental conditions during successive tests. The drought chamber is illustrated in Fig. 1. Inside dimensions are 28 inches high, by 24 inches wide, by 7½ feet long, providing sufficient space to accommodate five 14×19 inch flats. The bottom and sides are lined with ½-inch "Celotex" on the outside and ¼-inch three-ply wood on the inside, separated by an air space of 1½ inches. The front side is hinged to provide access to the interior of the chamber. The top is covered by a frame on which are mounted nine, 40-watt, 3,500° white, florescent lamps (L). A tubular automobile radiator (R) having a 3-inch core is mounted in the right end of the chamber to serve as a heating unit. Water held at a constant temperature in a 30-gallon insulated tank (T) is circulated by means of a centrifugal pump (P) driven by an electric motor. The temperature of the water in the tank is regulared by means of a 750-watt imersion heater (H) and a direct-action thermostat (S). The left end of the chamber is tapered to a 10¼-inch opening in which is mounted a 10-inch exhaust fan (F). Air drawn through the chamber at the rate of 0.5 mile per hour is heated to the desired temperature as it passes through the radiator. In operation, temperature in the chamber was held at ±80°±1°F (usually about 10° above the temperature of the surrounding air). Light intensity was held constant at 175-foot candles at the base of the chamber,

and relative humidity at 30 to 35%. No device was necessary for humidity control since the normal relative humidity in the basement room in which the chamber was located was 30% or less at 80° F. Occasional sprinkling of the floor was sufficient to keep the humidity within the desired limits. A recording hygrothermograph was used to record the temperature and relative humidity.

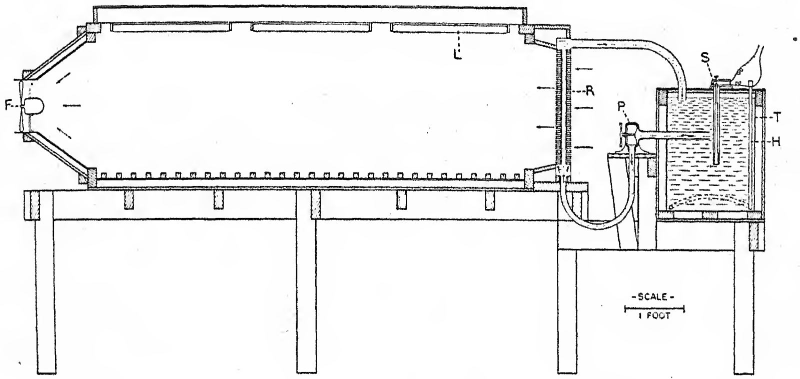


FIG. 1.—Sectional view of the chamber in which grass seedlings received controlled soil drought treatments. F, exhaust fan; L, 40-watt, 3,500° white, florescent lamp; R, tubular, 3-inch core, automobile radiator; P, centrifugal circulator pump; S, direct-operating thermostat; T, 30-gallon tank; H 750-watt immersion heater. The arrows indicate the direction of air movement through the chamber.

A few hours before a drought treatment began, the soil in the flats in which the seedlings were growing was saturated with water. Immediately before being placed in the chamber the flats were made up to equal net weights with additional water. The plants were held in the drought chamber for 6 to 9 days without further watering. During the drought test the locations of the flats in the chamber were changed twice daily to minimize positional effects. It was found that the most reliable index of the drought intensity necessary to produce differential survival of seedlings was to allow the plants to reach a state of desiccation in which the leaves and upper portions of the stems were dry and brittle while the bases of the stems were still slightly tough. At the end of the drought treatment the moisture content of the soil varied from 3 to 4%, while the wilting point of the soil used was 6.5%.

Following the drought treatment the plants were returned to the greenhouse, the soil was saturated with water, and the dry leaves and stems clipped about 1 inch above the soil. Trials had shown that removal of the dead aerial portions of the seedlings prevented spread of decay from the dead seedlings to the remaining living but weakened survivors by favoring free air circulation at the surface of the soil. After a recovery period of 2 to 3 weeks under optimum growing conditions, survival data were recorded. Seedlings surviving the drought treatment had by this time produced new leaves. The ratio of surviving plants to the number entering the test was used as the index of drought resistance of a particular strain or species. The appearance of smooth brome seedlings in series No. 22 as the drought treatment began and following a 3-week recovery period after the treatment is shown in Fig. 2.

All quantitative data presented have been analyzed statistically by the variance method. Each survival value in one test is an average of five replications with 25 seedlings in each replication.

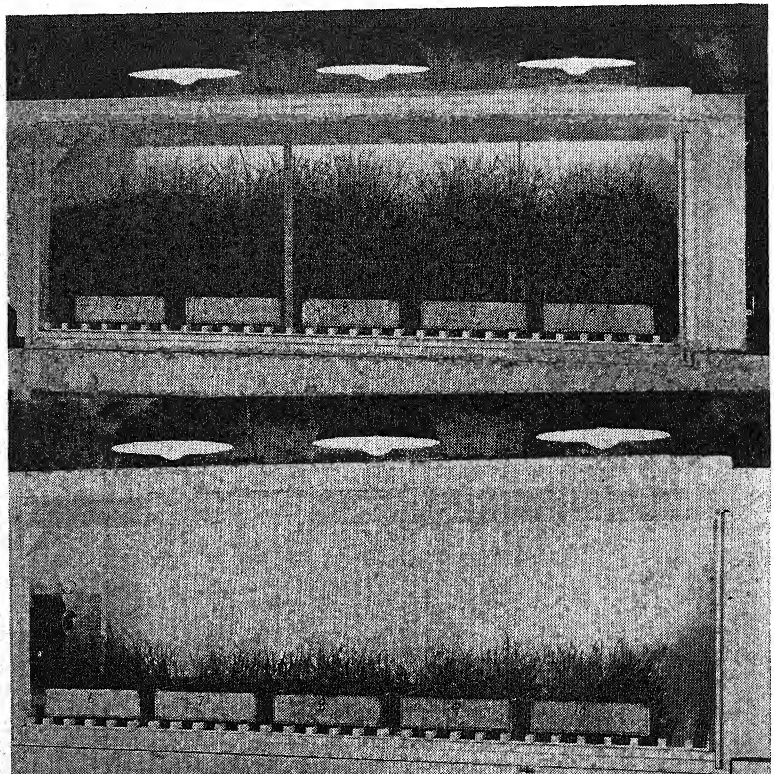


FIG. 2.—*Above*, appearance of smooth brome seedlings in test No. 22 (Table 3) as they were placed in the chamber for a critical soil drought treatment. *Below*, seedlings of the same test which had survived the drought treatment after removal of the dead top growth and a 3-week survival period in the greenhouse. At the time this test was made the source of illumination was three 200-watt tungsten lamps shown mounted above the chamber.

RESULTS

The reactions of seedlings of various strains of meadow foxtail, *Alopecurus pratensis* L., tall oatgrass, *Arrhenatherum elatius* (L.) Mert., and Kock., orchard grass, *Dactylis glomerata* L., meadow fescue, *Festuca elatior* L., and slender wheatgrass, *Agropyron trachycaulum* (Link) Malte to the soil drought treatment are shown in Table 1. Significant differences were shown between the survival values of the strains of all but the last two species. With the exception of the Akaroa strain of orchard grass, which is known to be nonresistant to drought, survival data of these strains under field conditions are not

available. The strains of orchard grass, SCS2566(Wales), SCS2569 (Sweden), and a Beltsville, Md., composite were equally resistant to the treatment. As far as comparisons are possible, however, the species survival was about what might be expected under conditions of critical drought in the field. Orchard grass and tall oatgrass gave average seedling survival of 67.9 and 68.3%, respectively, compared with 51.3% for meadow foxtail, 8.0% for meadow fescue, and 35% for slender wheatgrass. The latter value is probably low to be representative for slender wheatgrass as a species since seedlings of the strain Utah 12–26 gave lower than average survival when this strain was tested against other strains of the same species. Strain Utah 12–26 of slender wheatgrass was used as a check strain in most of the drought tests.

TABLE 1.—*Percentage seedling survival of species and strains of grasses following a controlled soil drought treatment.*

Species and strains	Average percentage survival	
	Strains	Species
Meadow foxtail, *Alopecurus pratensis:*		
Wash. 38 Blk	58*	
Wash. 38PR41	34	51.3
Oregon commercial	62	
Tall oatgrass, *Arrhenatherum elatius:*		
Oregon commercial	74	
P. I. 125,667	51	68.3
Shatterproof	80	
Orchard grass, *Dactylis glomerata:*		
Akaroa	47	
Oregon No. 8	80	
Oregon 14–36	72	
P. I. 119,638	54	67.9
SCS 2566	71	
SCS 2569	77	
Composite	74	
Meadow fescue, *Festuca elatior:*		
Wash. 37	6	8.0
Alta Fescue	10	
Slender wheatgrass, *Agropyron trachycaulum:*		
Utah 12–26	35	35.0

*Difference necessary for significance between two strain survival values at the 0.05 level of significance = 18%.

Seedling survival data are presented in Table 2 for nine strains of crested wheatgrass, *Agropyron cristatum* (L.) Gaertn., three of slender wheatgrass, two of blue wildrye, *Elymus glaucus* Buckl., and one each of *A. sibericum* and Russian wildrye, *E. junecus* Fisch. A wide range of survival was observed in the crested wheatgrass strains, i.e., from 28% for P. I. 119,599 (early) to 96% for the strain Pull.–59 (U. S. S. R.). The Fairway selection Nebraska 96–296 gave a survival of only 66% compared with 94% for the other Fairway selection

Nebraska 96–349. While the survival of seedlings of the strains Pull.–3358 (Washington) (83%) and Nebr. 1776 (80%) was less than for Pull.–59 (96%), the differences were not statistically significant. Of the slender wheatgrass strains Utah 12–26 gave a significantly lower seedling survival than Utah20–2 and a value lacking only 1% of being significantly lower than Utah S12–26. The latter strain was produced from plants of Utah 12–26 surviving earlier drought tests and suggests a possibility of using this technic for selecting plants for drought resistance. Although the *E. glaucus* strains differ by only 15%, the difference agrees with field observations on the reactions of these two strains to drought. That the drought treatment was more severe in this test than the one represented by the data in Table 1 is indicated by the lower survival value of the slender wheatgrass strain Utah 12–26 which gave 35% survival in the first test described and only 2% survival in the latter. The average species survival values in this test agree with their expected behavior under conditions of field drought, except that the susceptible strains of crested wheatgrass resulted in a lower value for this species than for Russian wildrye. In most areas where both

TABLE 2.—*Percentage seedling survival of species and strains of Agropyron and Elymus following a controlled soil drought treatment.*

Species and strains	Average percentage survival	
	Strains	Species
Crested wheatgrass, *A. cristatum:*		
Neb. 96–287	88*	
Neb. 96–296 (Fairway Sel.)	66	
Neb. 96–324	91	
Neb. 96–349 (Fairway Sel.)	94	
P. I. 119,599 (early)	28	73.6
P. I. 119,599	36	
Pull-59	96	
Pull-3358	83	
Nebr. 776	80	
Slender wheatgrass, *A. trachycaulum:*		
Utah 12–26	2	
Utah S12–26	22	16.7
Utah 20–2	26	
Agropyron sibericum:		
S. C. S. 2920–37P	70	70.0
Blue wildrye, *E. glaucus:*		
Wash. 39PR151	20	
Wash. 37S459	4	12.0
Russian wildrye, *E. junceus:*		
Wash. Sp. B	82	82.0

*Difference necessary for significance between two strain survival values at the 0.05 level of significance = 21%.

species are adapted, commercial crested wheatgrass would probably be slightly more resistant to drought than Russian wildrye.

Seedling survival of 14 strains of smooth bromegrass, *Bromus inermis* Leyss, and the check strain of slender wheatgrass Utah 12-26 is given in Table 3. These data are taken from three tests run at different seasons of the year, the majority of the strains appearing in each series. The figures at the bottom of the table show that for significance at the 0.05 level two strains must differ by 20% in tests 9 and 16 and by 16% in test 22. Significant differences between the

TABLE 3.—*Average percentage survival of the seedlings of Bromus inermis selections in controlled soil drought treatments.*

Selection	Percentage survival: Test number 9	16	22	Average of tests
Bromegrass, *B. inermis:*				
Neb. 80–1258	69*	47*	68*	61.3
Neb. 89–1842	71	60	—	65.5
Neb. 90–1706	75	64	45	61.3
Neb. 91–1678D	77	67	66	70.0
Neb. 96–20D	60	38	59	52.3
Neb. 96–23C	70	59	52	60.3
Neb. 96–249F	57	50	64	57.0
Neb. 98–1677	76	64	55	65.0
Wash. 38PR151	17	21	—	19.0
Wash. 38PR203	74	—	57	65.3
F. C. 22,435	31	8	17	18.7
Parkland brome	41	27	41	36.3
Superior brome	—	—	39	
Utah 9–26	68	48	—	58.0
Slender wheatgrass, *A. trachycaulum:*				
Utah 12–26	51	4	17	24.0

*Difference necessary for significance between two survival values at the 0.05 level of significance in test 9, 20%; test 16, 20%; and test 22, 16%.

average survival values for certain selections are apparent in each experiment. Strains included in more than one test behaved rather consistently. In test 16, however, the Nebraska strain 96–20D showed significantly less resistance to the drought than strains showing the highest survival values. As a group, the Nebraska strains gave high survival values. Separation of the individual strains of this group is not possible from the statistical standpoint, but it is interesting to note that Nebraska 91–1678D gave the highest seedling survival in tests 9 and 16 and only 2% less than highest in test 22 for the highest strain average (70%) in the three tests. Strains 96–20D and 96–249F gave the lowest average survival values, 52.3 and 57.0%, respectively.

Only 36.3 and 39.0% of the seedlings of Parkland and Superior bromes, respectively, survived the drought treatments. Newell and Keim (11) rated these two varieties as "poor" in drought and heat tolerance. The strains Washington 38PR151 and F. C. 22,435 were more susceptible to drought than any of the other smooth bromegrasses tested. Nonresistant *A. trachycaulum* strain Utah 12–26 gave low survival values in all three tests compared with the better smooth bromegrass strains.

Another illustration of differential strain response is presented in Table 4 in which seedling survival data are given for 14 strains or seed sources of crested wheatgrass, and one strain each of slender wheatgrass and Russian wildrye subjected to the drought treatment in the usual manner and after a preliminary hardening drought. The hardening treatment consisted of allowing the seedlings in one set of five flats to reach the permanent wilting point under greenhouse conditions by withholding water and then permitting the plants to recover for one week with optimum soil moisture before the critical drought treatment was applied. The seedlings in the hardened series were 1 week older than those of the unhardened series at the beginning of the critical stage of drought.

TABLE 4.—*Comparison of the effects of a controlled soil drought treatment on the relative survival of drought-hardened and unhardened grass seedlings.*

Species and strains	Percentage survival in seedling treatment preceding the critical soil drought	
	Unhardened	Hardened
Crested wheatgrass, *A. cristatum:*		
A-2513	96*	93*
A-2504	97	90
A-1874	54	58
A-1770	58	73
A-1849	37	26
A-1113	58	31
Commercial 1	98	94
Commercial 2	93	91
Commercial 3	98	92
Commercial 4	94	96
Commercial 5	97	91
Commercial 6	95	94
Commercial 7	98	95
P. I. 119,599	59	55
Slender wheatgrass, *A. trachycaulum:*		
Utah 12–26	18	15
Russian wildrye, *E. junceus:*		
Wash. Sp. Bl.	95	92

*Difference necessary for significance between two strain survival values at the 0.05 level of significance, unhardened, 15% and hardened, 14%.

The data indicate that the hardening process did not affect the relative survival of most of the strains included in the test. While there may have been an actual hardening of the seedlings by the preliminary soil drought, only one strain of crested wheatgrass (A–1770) showed definite signs of increased resistance as a result of the treatment. Strains A–1113 and A–1849 apparently became more susceptible as a result of the preliminary hardening. Survival values were similar in both series for the slender wheatgrass and Russian wildrye strains. Comparison of individual survival values shows that the seedlings from commercial seed sources were more resistant to the treatment (91% or better survival) than all but two of the selections of crested wheatgrass, A–2504 and A–2513. Plant Introduction 119,599, which was also included in the test summarized in Table 2, again proved nonresistant. The Russian wildrye strain survived in both series in about the same manner (95% and 92%) as the better *A. cristatum* strains. Seedling survival in *A. trachycaulum* Utah 12–26 was the low in both series, 18% and 15%, indicating that the drought treatment was severe. The treatment was not severe enough, however, to give a satisfactory differential survival of the drought resistant crested wheatgrass strains.

Tests have been run to determine the effect of (a) age of seedlings at the time of the drought treatment, (b) of soil fertility, and (c) of the newsprint bands used on the relative survival of strains to the controlled drought test. Neither high nor low soil fertility, nor the presence or absence of newsprint bands affected the relative survival of grass seedlings. Age of seedlings at the time the drought treatment began, however, had an important bearing on their survival. In two series, involving 4,000 seedlings each of slender wheatgrass and smooth brome, no significant differences could be found between strains if their seedlings received the drought treatment when only 1 month old. Satisfactory differentiation between strains within either species resulted when the seedlings were 6 weeks or 2 months old at the beginning of the drought treatment.

DISCUSSION

The data presented are representative of the results obtained on the reaction of grass species and strains to the controlled soil drought treatment. Over 96,000 seedlings of more than 50 native and introduced species have been studied during the process of development and standardization of the test. Species and strain response of the seedlings in all critical, controlled drought treatments has been similar to that illustrated in Tables 1 to 4. In general, the average relative survival values for species have been in agreement with available information of their behavior under conditions of severe field drought. More important, however, from the standpoint of possible production of drought resistant grass strains, is the wide range of seedling survival found between strains within species.

The agreement between the drought reaction of some of the smooth brome strains in both the field and the controlled drought tests summarized in Table 3 suggests that strain differences observed in other species may also be due to actual differences in drought resistance.

Differences in soil drought resistance of strains within species as found in this study and the wide range of drought and heat tolerance observed by Newell and Keim (11) in a study of 24 smooth brome strains do not support the statement made by Vasiliev (18) that it is not possible to breed for soil drought resistance in plants. Differential drought survival of strains within grass species also means that caution must be exercised in characterizing a species as to drought resistance from observations on plants from a single seed source or strain.

The average seedling survival values for grass species in the controlled drought tests have generally agreed with the expected behavior of mature plants under conditions of critical field drought. That the resistance to drought may be different in the seedling stage than in well-established plants is illustrated, however, by results with western wheatgrass, *Agropyron smithii* Rydb. This species would usually be listed as at least as drought resistant or more so than slender wheatgrass. In an experiment involving both species, the average survival of the seedlings of western wheatgrass was only 2% compared with 27% for those of slender wheatgrass. Mueller and Weaver (10) rated *A. smithii* in the top four in a list of 12 mixed-prairie grasses on the basis of observations of drought resistance of mature plants on the prairie. The seedlings of this species were, however, the most susceptible to drought of any of the 12 species in drought tests. Slow root development in *A. smithii* seedlings was suggested by Plummer (13) to be the reason for their susceptibility to drought in this stage. Cook (4) has shown that the extent of the root system produced during the seedling year was directly related to the ability of eight of the smooth brome strains presented in Table 3 of this paper to resist the drought treatment.

In the first controlled soil drought tests, attempts were made to arrive at the correct drought treatment to give a differential survival between grass species or strains by allowing the seedlings to wilt until a definite, calculated soil moisture had been reached in the soil in which they were grown. Such a procedure was followed by Carroll (3) in his soil drought tests with turf grasses. This criterion of drought intensity was abandoned, however, when it was found that with the same soil moisture contents at the end of the drought treatment an average survival of all plants in one test might be 80% and in another only 20%. Careful observation of the seedlings as wilting becomes severe and their removal from the drought chamber as soon as all leaves become dry and brittle has usually resulted in a satisfactory drought treatment.

Experiments run at different seasons of the year have given uniform results if the age of the seedlings at the beginning of the drought treatment is between 6 and 8 weeks and if only species whose seedlings have similar growth rates are included in a given test. When species whose seedlings develop slowly, e. g., gramas and bluestems, are included in the same test with species whose seedlings develop rapidly, e. g., bromes and most of the wheatgrasses, the former species are usually stunted and give lower survival after the drought than is shown by the same seedlings in the field. The most satisfactory

tests have been those in which all of the 16 strains are of the same species. The chief value of the technic described will be as a quantitative means of determining seedling drought resistance between strains within grass species if further field tests confirm the strain differences observed.

SUMMARY

A direct method for determining soil drought resistance to supplement field tests is described. Grass seedlings are grown for 6 to 8 weeks in the greenhouse and then given a soil drought treatment lasting from 6 to 9 days by placing them in a chamber designed to maintain constant environmental conditions of temperature (80°F), light (175 foot-candles), relative humidity (30 to 35%), and air velocity (0.5 mile per hour). Seedlings surviving the drought treatment are allowed to recover under favorable growing conditions in the greenhouse. The percentage of plants renewing growth during the recovery period is used as the index of relative drought resistance of a species or strain.

In preliminary trials the reaction of over 96,000 grass seedlings to the controlled soil drought treatment has been studied. The average survival values for species have been in agreement with their known behavior under natural conditions of critical drought. More important, however, was the wide variation observed between strains or seed sources within species. Although field data are available for only a small number of the strains tested, satisfactory correlation between field and greenhouse survival was obtained where comparisons were possible. The variability of strains within species suggests the possibility of breeding for soil drought resistance in grasses and the dangers of characterizing a species as to drought resistance from observations on a single strain or seed source.

LITERATURE CITED

1. AAMODT, O. S. A machine for testing the resistance of plants to injury by atmospheric drought. Can. Jour. Res., 12:788–795. 1935.
2. ———— and JOHNSTON, W. H. Studies on drought resistance in spring wheat Can. Jour. Res. C, 14:122–152. 1936.
3. CARROLL, J. C. Effects of drought, temperature and nitrogen on turf grasses. Plant Physiol., 18:19–36. 1943.
4. COOK, C. W. A study of the roots of *Bromus inermis* in relation to drought resistance. Ecology, 24:169–182. 1943.
5. GLENDENING, GEORGE E. Development of seedlings of *Heteropogon contortus* as related to soil moisture and competition. Bot. Gaz., 102:684–698. 1941.
6. HABER, S. E. A study of drought resistance in inbred strains of sweet corn, *Zea mays* var. Rugosa. Iowa Agr. Exp. Sta. Res. Bul. 243. 1938.
7. HUNTER, J. W., LAUDE, H. H., and BRUNSON, A. M. A method for studying resistance to drought injury in inbred lines of maize. Jour. Amer. Soc. Agron., 28:694–698. 1936.
8. MCALISTER, DEAN F. A technic for growing seedlings of grass and other plants for field transplanting. Jour. Amer. Soc. Agron., 35:836–840. 1943.
9. MAXIMOV, N. A. The plant in relation to water, a study of the physiological basis of drought resistance. Translated by R. H. YAPP., Allen and Unwin, London. 1929.
10. MUELLER, IRENE M., and WEAVER, J. E. Relative drought resistance of seedlings of dominant prairie grasses. Ecology, 23:387–398. 1942.

11. NEWELL, L. C., and KEIM, F. D. Field performance of bromegrass strains from different regional sources. Jour. Amer. Soc. Agron., 35:420–434. 1943.
12. NEWTON, R., and MARTIN, W. M. Physico-chemical studies on the nature of drought resistance in crop plants. Can. Jour. Res., 3:336–427. 1930.
13. PLUMMER, A. PERRY. The germination and early seedling development of twelve range grasses. Jour. Amer. Soc. Agron., 35:19–34. 1943.
14. SAKS, A. I. On several direct methods of evaluating wheat varieties as regards their drought resistance. (Russian with English Summary) Bull. Acad. Sci. U. R. S. S. Cl. Sci. Math. et Nat. Ser. Biol., 1941:163–175. 1941. (Abstract in Biol. Abs., 16:2503. 1942.)
15. SCHULTZ, H. K., and HAYES, H. K. Artificial drought tests of some hay and pasture grasses and legumes in sod and seedling stages of growth. Jour. Amer. Soc. Agron., 30:676–682. 1938.
16. SHIRLEY, HARDY L. A method for studying drought resistance in plants. Science, 79:14–16. 1934.
17. ———— and MEULI, LLOYD J. Influence of moisture supply on drought resistance of conifers. Jour. Agr. Res., 59:1–21. 1939.
18. VASILIEV, I. M. Plant Physiology in relation to drought control. Soc. Zern. Khoz. 1–2:10–12. 1932. (Abstract in Herb. Ast., 3:226–227. 1933.)
19. WHITMAN, WARREN C. Seasonal changes in bound water content of some prairie grasses. Bot. Gaz., 103:38–63. 1941.

SEED DORMANCY AND GERMINATION IN SOME NATIVE GRASSES[1]

C. J. Coukos[2]

In the past decade native grasses have come into widespread use for revegetating grazing lands in the Great Plains. Observations have also indicated possible uses for certain native grasses in several states of the upper Mississippi Valley.

Of special significance in a soil conservation program is the ability of some native grasses, such as little bluestem, to establish themselves on droughty, severely eroded uplands where cultivated grasses fail to develop satisfactory stands. The bluestems and certain other native grasses are known to be highly nutritious when properly utilized (1, 2),[3] and recent unpublished data secured from clipping studies at the Soil Conservation Service nursery, Elsberry, Mo., indicate favorable herbage yields. Most of the warm-weather perennial native grasses exhibit maximum growth during the summer period, while the majority of the cultivated grasses mainifest greatest productivity in the spring and fall and are relatively dormant during the hot months.

Early investigators (4) generally experienced seeding failures, largely because little was known about the germination habits of these grasses. In some early seedings by the Soil Conservation Service in the upper Mississippi Valley, poor stands of bluestems and other native grasses were obtained in nursery plots and field trials. At first it was believed that the poor stands resulted from use of low-quality seed; yet sowing seeds of high caryopsis count did not always assure good stands. This suggested the possibility that prolonged seed dormancy may be an important factor in establishment.

Some literature is available on seed dormancy and germination habits of several native grasses, but little published material is found on this subject in regard to seeds of big bluestem, *Andropogon furcatus* Muhl., little bluestem, *Andropogon scoparius* Michx., Indian grass, *Sorghastrum nutans* (L.) Nash., and side-oats grama, *Bouteloua curtipendula* Michx., the species involved in this report.

Data[4] and observations presented in this paper cover degree of seed dormancy and effects of various storage conditions in overcoming dormancy and preserving seed viability.

Data on the germination of bromegrass, *Bromus inermis* Leyss, are also presented. This grass was used for purposes of comparison.

EXPERIMENTAL PROCEDURE

Three different storage room conditions were selected for the storage study,

[1]Contribution from Soil Conservation Nursery, Elsberry, Mo. Received for publication November 17, 1943.

[2]Assistant Agronomist.

[3]Figures in parenthesis refer to "Literature Cited", p. 345.

[4]In conjunction with this study, work was conducted on testing various methods to overcome seed dormancy in the field establishment of these native grasses. The results of this work will be reported in a separate paper.

namely, (a) a barn loft, (b) a laboratory room,[5] and (c) a cold storage room. Temperature recordings for these rooms are given in Table 1. The storage containers consisted of small cotton bags and quart fruit jars with tight screw lids. About ½ pound of seed of each sample was stored in each container. The germination tests were run in the greenhouse using duplicate samples of 100 seeds each. A sterilized peat and sand medium was found to be satisfactory for testing these seeds under greenhouse conditions. Germination was observed over a 4-week period. Rough seeds with glumes and attached appendages were used, and germination results were recorded on a 100% caryopsis content basis. The seeds were collected by hand from nursery plots or from native habitats in Missouri and Illinois late in the fall when seeds were fully mature.

Before being placed in their respective containers and storage locations, all the seed samples were thoroughly dried in the greenhouse for several days and again at room temperature where relative humidity was low. It is assumed therefore that the moisture content of the seeds was uniformly low and whatever changes might have occurred during the study were influenced by the atmospheric conditions in the various storage rooms. Relative humidity records were kept on all the storage rooms in 1939 and 1940 as shown in Table 1. The average relative humidity that prevailed at room temperature is designated in this discussion as low and variable and that in cold storage as high and rather constant.

TABLE 1.—*Average annual temperatures and relative humidities of three different seed storage rooms and outdoors for the years 1939 and 1940, Elsberry, Mo.*

Storage room	1939				1940			
	Temperature, °F		Relative humidity, %		Temperature, °F		Relative humidity, %	
	Av. min.	Av. max.	8 a.m.	Noon	Av. min.	Av. max.	8 a.m.	Noon
Barn loft...	50	62	56	40	49	63	58	38
Room......	61	80	38	29	61	81	36	31
Cold storage	33	41	81	83	34	42	84	80
Outdoors...	44	66	77	53	45	65	77	54

STORAGE TEMPERATURE EFFECTS ON DORMANCY AND PRESERVATION OF VIABILITY

Exploratory storage tests, which revealed indications of dormancy, were conducted with all four of the native grasses in 1937. More comprehensive tests were inaugurated late in the fall of 1938. In order to supplement the results of these trials, other samples were placed under test in 1939 and 1940. The results thus obtained with the 1939 and 1940 accessions confirm the germination trends of the 1938 tests which are discussed in this paper.

Seed dormancy, regardless of causes, is referred to here as of prolonged or brief duration. The former pertains to dormancy of seeds that persists sufficiently long to prevent satisfactory germination the

[5]Referred to hereafter as "room temperature".

first spring after the fall harvest; the latter where dormancy persists only for 2 or 3 months after harvest and the seeds germinate readily by spring.

In comparing the effects of the three storage room conditions on germination, it was found that in practically all cases there was little significant difference between the results of storage in barn loft and under room temperature, but considerable difference between these two and refrigerator storage. So only the data of room temperature and refrigerated room (cold storage) are compared. The germination data covered a period of 38 months for the four native grasses and 25 months for bromegrass and a Kansas selection of little bluestem (Table 2). The data for these six grasses are charted in Fig. 1.

TABLE 2.—*Percentage germination of one cultivated and five native grasses following 2 to 38 months under different storage conditions.*

Grass	Months in storage in																			
	Bag										Jar									
	2	6	10	14	18	22	25	31	35	38	2	6	10	14	18	22	25	31	35	38
At Room Temperature																				
Little bluestem (Mo. collection)	0	0	3	21	36	26	52	48	25	12	0	6	0	27	42	26	65	78	43	38
Little bluestem (Kan. selection)	27	79	46	89	98	87	100	–	–	–	–*	70	47	91	100	98	100	–	–	–
Big bluestem	7	6	31	59	76	58	70	40	14	14	0	7	37	74	90	70	70	100	74	74
Indian grass	19	7	1	44	45	–*	93	64	26	29	–*	13	–*	52	69	–*	77	54	22	54
Side-oats grama	54	70	24	40	52	20	10	6	2	0	50	56	26	36	70	63	54	80	74	56
Bromegrass	92	88	80	86	94	55	15	–	–	–	–*	91	82	83	100	87	70	–	–	–
In Cold Storage																				
Little bluestem (Mo. collection)	0	19	4	21	48	32	56	42	22	14	0	4	4	13	–*	12	52	47	40	58
Little bluestem (Kan. selection)	12	81	60	84	96	84	96	–	–	–	–*	75	50	90	88	63	58	–	–	–
Big bluestem	3	30	45	56	43	30	42	30	15	6	3	–*	1	15	–*	18	53	49	48	66
Indian grass	10	4	0	49	49	–*	25	20	3	10	–*	7	1	45	–*	–*	25	20	7	4
Side-oats grama	4	25	2	5	55	46	37	28	24	21	22	22	2	2	–*	6	11	54	40	64
Bromegrass	86	82	84	84	91	90	84	–	–	–	–*	91	82	88	100	90	82	–	–	–

*Germination tests were not run at this period.

BIG BLUESTEM

Six field collections from Missouri were studied in the storage tests. Dormancy and germination characteristics of one representative accession are shown in Fig. 1.

Germination of big bluestem seeds under room temperature conditions was negligible at the beginning of the tests and continued low for several months. A number of seeds sprouted after about 10 months in bag and jar storage, or 12 months after harvest. The rate of germination increased through the fall and reached maximum by the second spring, or after about 18 months in storage.

Cold storage in the bag hastened the breaking of dormancy, but the break did not occur sufficiently early (10 months) to influence results obtained from seeding in the first spring after seed harvest.

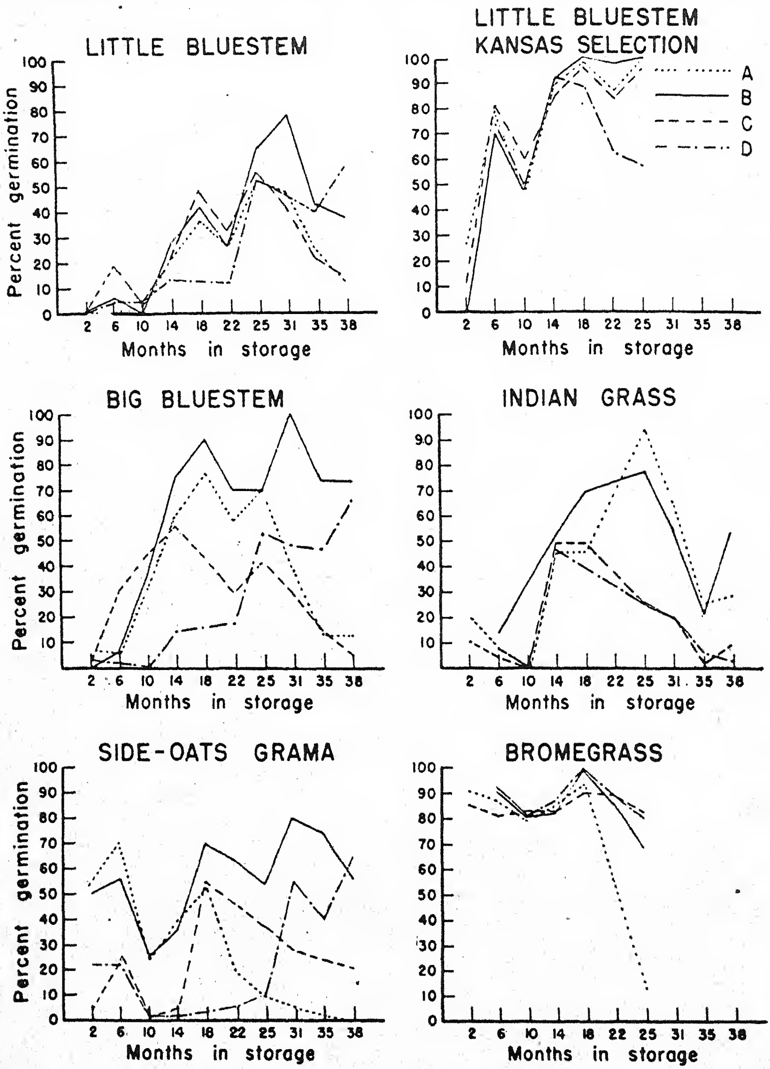


FIG. 1.—Germination trends of five native grasses and one cultivated grass resulting from 2 to 38 months' storage under (a) room temperature in cloth bag, (b) room temperature in sealed jar, (c) refrigerator temperature in the bag, and (d) refrigerator temperature in the jar.

Cold storage in jars prolonged dormancy. On the other hand, this type of storage preserved the viability of seeds 10 months longer than cold storage in bags.

After breaking dormancy, which occurred from 14 to 22 months after seed harvest depending on room and container conditions, seeds remained viable for another period of 14 to 18 months; from then on viability decreased rapidly under all storage conditions except jars in cold storage.

LITTLE BLUESTEM

Six accessions of this species were also tested. Five were field collections from various areas in Missouri. The sixth was a Kansas improved selection. Prolonged dormancy was found in all Missouri collections; however, the Kansas strain showed signs of possessing brief dormancy. The germination trend of the field collections as well as the Kansas strain is illustrated in Fig. 1.

Cold storage in the jar delayed germination considerably in the Missouri field collection. Satisfactory germination was obtained only after about 25 months in storage, although the viability of the seed was preserved longer under this treatment. Even after 38 months in storage the germination was still about 60%. Cold storage in the bag showed a slight tendency of inducing germination after 6 months in storage, though an appreciable break of dormancy did not occur until 18 months later. Fair germinability was retained for about 11 months after overcoming dormancy, but thereafter viability decreased rapidly until only 14% germination was recorded at the end of the test period.

Seed stored under room temperature conditions both in the bag and in the jar did not show appreciable signs of dormancy breaking until 18 months after storage. Thereafter good viability was retained for about 13 months under bag conditions then it dropped to 22% at 35 months and to 11% at 38 months. Viability after break of dormancy was retained longer at room temperature in the jar than in the bag. A small drop in germination occurred at the 35-month interval, but at the end of the test a fair germination was still recorded. Fig. 1 shows a decrease in germination at the end of the 22-month storage period. This drop apparently was caused by induced secondary dormancy[6] as a result of high summer temperatures that prevailed in the greenhouse during the germination test. This decrease in germination may also be observed in other species.

The Kansas selection of little bluestem was the only strain of this species that possessed brief dormancy. The seed used was produced at Elsberry, but its original source was Manhattan, Kan. Some dormancy was shown after 2 months in storage but by spring as high as 80% germination was obtained. In field trials, also, this strain was the only one to give good stands when seeded the first year after harvest.

INDIAN GRASS

Cold storage conditions prolonged dormancy of Indian grass about as long as room temperature (14 to 18 months), but the viability of the seeds was sharply reduced after breaking of dormancy under the cold storage treatment. The detrimental effect of jar storage was

[6]After seed dormancy has been broken, it is possible to cause dormancy again by changing germination temperature conditions. This is referred to as induced secondary dormancy (8).

unusual, for in all the other grasses jar storage maintained high viability for several months after dormancy was broken.

Under room temperature storage, dormancy was retained for 14 to 18 months. Indian grass was similar to big bluestem in this respect, but higher germination of the former was obtained upon break of dormancy. The viability of the seeds was preserved longer in the jar than in the bag.

SIDE-OATS GRAMA

The germination data for side-oats grama represent a field collection from a bluff area in western Illinois.

Seeds of side-oats grama proved more sensitive to storage temperatures than seeds of other species under observation. Cold storage in the bag prolonged dormancy to 14 months, whereas dormancy broke in 2 to 6 months under room temperature conditions, both in bag and jar. Under cold storage in the jar, dormancy continued to 25 months but broke during the 31-month test period, and good germination persisted even at the end of the test.

In maintaining good germination after overcoming dormancy, the jar container proved superior to the bag. Fig. 1 shows that when seeds were stored in jars, good germination prevailed for at least 38 months, but in the bag viability decreased abruptly soon after break of dormancy.

Sensitivity to germination temperatures prevailing in the greenhouse is strikingly exhibited in the chart. Germination dropped significantly in the summer of 1939 (10 months in storage) and the summer of 1940 (22 months in storage) due to high greenhouse temperatures that probably induced secondary dormancy.

BROMEGRASS

A Kansas-type bromegrass was used in the study. This cool-weather cultivated grass was incorporated in the study to compare its response to storage conditions and germination behavior with those of the native grasses. This species was added to these tests in the fall of 1939, hence data for only 25 months were obtained.

The results show that bromegrass possessed no dormancy, either brief or prolonged. Although some degree of brief dormancy is reported by other investigators for Kentucky bluegrass, orchard grass (7) and other cool weather grasses, this characteristic was not detected in samples of bromegrass studied at Elsberry, even including those tested shortly after harvest.

Bromegrass retained high viability throughout the period of observation (25 months) under all storage and container conditions, except room temperature storage in the bag. There the viability decreased rapidly after 18 months.

DISCUSSION

In the past, attempts at establishing native grasses from seed have been commonly characterized by erratic and disappointing results. Seeding failures have been common and have occurred without satis-

factory explanation. While many factors, such as climatic, cultural, seed character, may influence the establishment of any grass, the set of factors particularly peculiar to the native grasses are those pertaining to seed character. Of the several pecularities of native grass seeds, the character of dormancy is primary in influencing stand establishment.

Laboratory studies by other investigators have shown that, while some degree of seed dormancy often exists in freshly harvested seeds of cultivated grasses (7), distinct and prolonged seed dormancy has very often occurred in seeds of several native grasses, such as *Oryzopsis hymenoides* (5), *Danthonia spicata* (6), and others.

The germination data that are presented in this paper were obtained entirely from laboratory tests. Seeds of all four species from 1937, 1938, and 1939 field collections from habitats in Missouri and Illinois, however, produced very thin stands the following springs when they were planted in small plots, despite the fact that the seeding rates were corrected according to the caryopsis content. On the other hand, seeds of grasses that were 2 years old and apparently not affected by dormancy produced comparatively good stands. These data and observations definitely show the importance of seed dormancy as an important factor in the establishment of native grasses under Missouri conditions and confirm the results obtained by the laboratory seed tests.

The germination curves illustrated in Fig. 1 bring out definitely the presence of prolonged dormancy in big bluestem, Indian grass, little bluestem, and in some ecotypes of side-oats grama. One strain of little bluestem is shown to possess only brief dormancy, meaning that after a period of about 6 months under barn loft or room temperature, dormancy was broken and the seeds germinated satisfactorily. This was the Kansas strain, sometimes referred to as the Aldous strain (3). This particular strain was the product of 3 years' selection work at the Kansas Experiment Station and it is likely that high germinability was secured coincidentally with other breeding factors. It is possible that bluestem ecotypes do not exhibit the same dormancy periods in both the Mississippi Valley and western habitats such as Kansas. With Missouri and Illinois ecotypes prolonged dormancy is typical, and has been affirmed by germination tests over a period of years with scores of seed samples gathered from all parts of Missouri and Illinois.

Comparatively low temperatures and low relative humidity that prevailed under jar cold storage conditions were responsible for prolonging dormancy in the seeds of all native grasses characterized with prolonged dormancy, except Indian grass. Dormancy prevailed as much as 14 months longer under these conditions than under bag cold storage conditions where low temperatures and high humidity prevailed. By the latter storage method appreciable germination was induced as early as 10 months after storage. Results of room temperature conditions, where temperature was comparatively high and humidity low, were somewhat different from those of cold storage, particularly under jar storage. Break in dormancy did not occur in either the bag or jar until about 12 months after storage.

Analyses of germination behavior of seeds of grasses that possessed either brief dormancy or no dormancy, such as the Aldous strain of little bluestem and bromegrass, respectively, showed that temperature and relative humidity differences had very little effect on either inducing or reducing germination for at least 2 years. After that period, signs of deterioration appeared in the seeds stored in the bag at room temperature.

The low temperature and low humidity conditions that prevailed in the jar cold storage maintained good viability in all seeds except Indian grass to the end of the tests 38 months after storage. Jar storage at the comparatively high room temperatures with low relative humidity likewise maintained high viability. Bag storage at low temperature and at room temperature did not prove nearly so successful in maintaining high viability after dormancy broke. This may be attributed to the high humidity under cold storage and fluctuating relative humidity combined with high temperatures which existed in room conditions.

In brief, it might be stated that, although low temperature and high humidity had a tendency to induce germination more rapidly and produce higher germination percentages than any other temperature-humidity combination, the difference was not sufficiently significant to be considered in overcoming prolonged seed dormancy difficulties. On the other hand, low and constant relative humidity and low temperatures as prevailed in the jar cold storage, or high temperatures with low relative humidity as prevailed in jar storage at room temperature, were influential in prolonging high viability in dormancy-free seeds or seeds that had after-ripened.

Examination of caryopses which failed to germinate in both greenhouse tests and field seedings showed that water was absorbed by the seeds, particularly in the embyro region.

Hammer mill processing, a type of mechanical scarification, tended to induce germination in dormant caryopses of all native grasses discussed in this paper. Even the slight scarification obtained by combining, as compared to hand harvesting, is effective in breaking dormancy in a large percentage of the caryopses of big and little bluestem. Acid scarification, both concentrated and diluted treatments, induced germination, but it was also observed that such treatments were detrimental to seeds that were dormancy-free.

Some of these evidences suggest that the seed coat affects dormancy. This seed coat restriction is not similar to dormancy of "hard" seeds as in many legumes, for these grass seed coats permitted entrance of water even in unscarified seeds. Perhaps the answer to the nature of dormancy in native grasses may lie in the theory of "gas-exchange" restrictions in seed coats or membranes (6,8).

SUMMARY

1. Germination tests conducted on numerous accessions of seeds of big bluestem, little bluestem, and Indian grass showed conclusively that these seeds possessed prolonged dormancy. Some collections of side-oats grama and a Kansas selection of little bluestem

possessed brief dormancy. Under ordinary storage conditions, seeds possessing prolonged dormancy give very low germination the first spring in laboratory tests, and consequently result in poor stands as observed in several plot seedings. Such seeds cannot be successfully used for spring sowing until the second spring after harvest. Seeds with brief dormancy may be used the first spring in field seedings.

2. Seeds of these grasses stored in either the barn loft or at room temperature in bags or in jars did not begin normal germination until from 14 to 18 months after harvesting. After dormancy broke, germination remained at a high average for several months. In most cases when seeds were stored in bags under these storage conditions, they retained good viability only for about 10 months after break of dormancy, while seeds stored in jars remained viable for at least 20 months after break of dormancy.

3. Dry cold storage extended the dormancy period of the species under trial except in some accessions of big bluestem. Cold storage in the bag shortened the life span of seeds after break of dormancy, but when the seeds were stored in jars the life span was extended for at least 38 months, except in the case of Indian grass in which case the life span was extended to 24 months.

LITERATURE CITED

1. Aldous, A. E. Management of Kansas permanent pastures. Kan. Agr. Exp. Sta. Bul. 272. 1935.
2. Anderson, Kling L. Deferred grazing of bluestem pastures. Kan. Agr. Exp. Sta. Bul. 291. 1940.
3. ————, and Aldous, A. E. Improvement of *Andropogon scoparius*. Jour. Amer. Soc. Agron., 30:862–869. 1938.
4. Wenger, Leon E. Soaking buffalo grass seed to improve its germination. Jour. Amer. Soc. Agron., 33:135–141. 1941.
5. Toole, Vivian K. The germination of seed of *Oryzopsis hymenoides*. Jour. Amer. Soc. Agron., 32:-33–41. 1940.
6. ————. Germination of the seed of poverty grass, *Danthonia spicata*. Jour. Amer. Soc. Agron., 31:954–965. 1939.
7. Sprague, V. G. Germination of freshly harvested seeds of several *Poa* species and of *Dactylis glomerata*. Jour. Amer. Soc. Agron., 32:715–721. 1940.
8. Davis, W. E. Primary dormancy, after-ripening, and the development of secondary dormancy in embryos of *Ambrosia trifida*. Amer. Jour. Bot., 17:58–76. 1930.

SEED SETTING IN RED CLOVER[1]

J. N. Bird[2]

ALTHOUGH red clover is the most commonly seeded legume hay species in eastern Canada, it frequently winterkills to such an extent that home-grown seed production is insufficient to meet the seeding needs of the following year. Unless there has been a substantial carryover of domestic seed from the previous year, it then becomes necessary to make up for the deficit by the use of imported seed. Crops produced from foreign-grown seed have generally proved less winterhardy than those from seed of domestic origin. It is therefore apparent that importation of seed may be one of the causes, as well as one of the results, of winterkilling of red clover in Canada.

Lying along the northern margin of the red clover region in North America, eastern Canada requires, and should be able to produce, the most winterhardy of red clover strains. While there still remains scope for much improvement in the winterhardiness of existing strains, it is obvious that such improvement will be ineffective in raising the standard of our domestic crop unless home-grown seed can be produced economically and in a sufficient quantity so as to render unnecessary the importation of seed from foreign sources.

Although density of stand and profusion of bloom may determine the lower and upper limits of seed yields per acre, wide fluctuations between such limits from season to season and from place to place may result from variation in the set of seed as indicated by the average number of seeds per head in samples drawn from the ripened crop. It is important, however, to realize that the number of seeds per head is dependent, in turn, upon the number of florets per head, their condition at the time of pollination and fertilization, and the number and activity of pollinating insects. The present study based upon number of seeds per head was undertaken with the hope that it might indicate by means of a seasonal trend the period of maximum seed setting of red clover in eastern Canada.

REVIEW OF LITERATURE

NUMBER OF FLORETS PER HEAD

Westgate, *et al.* (24)[3] reported a range of 35 to 150 florets in the red clover heads which they examined. Williams (29) referred to 105 florets per head as an average figure. In a later paper (30), he pointed out that the number might vary with the position of the head on the plant. It ranged from about 10 to nearly 300, the greatest number being usually on the main terminal heads which opened first, while the smallest number occurred on heads borne on the lower branches.

[1]Contribution from the Faculty of Agriculture, McGill University, Macdonald College, Que., Canada. Journal Series No. 188. Received for publication November 20, 1943.

[2]Lecturer in Agronomy. The author wishes to acknowledge assistance in this study received from the Entomology Department under the direction of Dr. F. O. Morrison.

[3]Figures in parenthesis refer to "Literature Cited", p. 356.

Hollowell (7) in a study of the influence of soil moisture on the seed setting of red clover grown in containers found a greater number of florets per head on plants grown under conditions of medium or low than under high soil moisture. Richmond (20) counted florets on 50 heads of red clover from each of three fields in Colorado and obtained averages of 100.46, 114.22, and 119.28 florets per head for these fields. Wexelsen (26) obtained a range of 70 to 150 florets per head in his investigations. Pammel and Clark (12) reported that they found more florets per head on the second crop of red clover than the first. Pedersen (17) obtained averages of 104, 108, 107, and 108 florets per head, respectively, from aftermath crops following cuttings on May 15, May 25, June 5, and June 15, as compared with 98 for the first crop.

CONDITION OF THE FLORETS

Both defective ovules and pollen grains have been reported in red clover. Westgate, *et al.* (24) found infertile ovules rather common in red clover, especially in the first crop, and apparently associated with moist soil and atmospheric conditions. However, Hollowell (7) concluded from his studies that, although infertile ovules might occur, they were apparently not caused by moisture conditions and were not present to a greater extent in the first than in the second growth. Wexelsen (26) found abnormal pollen rather common in red clover, but since very few of the 295 plants which he examined had less than 80% of good pollen, he did not consider the small percentage of poor pollen could have any serious effect on the fertilization of the crop.

The possible damage of red clover pollen by water has also received the attention of several investigations. Martin (8) found that pollen grains might remain in a resting condition for as long as 18 hours in cold damp weather. He maintained that the germination of pollen grains on the stigma was delicately adjusted to the water supply. Westgate, *et al.* (24) reported that pollen grains when placed in water burst almost instantly and on this account there could be little effective pollination while the flowers were wet with rain or dew. On the other hand, Hollowell (7) found that, although many pollen grains burst immediately after immersion, some were apparently unaffected by water at the end of ten minutes. Contrary to the opinion held by Martin, his experiments led him to the belief that the moisture surrounding the pollen grain on the stigma was of little consequence in its functioning. Wexelsen (27) tested the pollen of a large number of plants to determine its reaction to water in the hope of finding certain pollen types that could withstand moisture without being destroyed. However, the pollen of all plants which he investigated behaved similarly, bursting when brought in contact with water.

Sylven (23) found that sunshine combined with appropriate atmospheric moisture provided the most favourable weather for seed setting of red clover. A long period of heat with extremely dry air during the blooming period was harmful, the fewer heads tending to dry without attempting to form seeds. The low set of seed obtained in periods of cold rainy weather was conditioned by a lack of pollinating insect visitors.

POLLINATION

Westgate, *et al.* (24) and Williams (29) have reviewed observations of earlier workers on red clover pollination by bees and other insects. Although it has been recognized that the pollination may be effected by several genera of insects, the

bumble bee has been generally considered the principal pollinating agent. It has been regarded as the most regular insect visitor, working rapidly and remaining active under weather conditions sufficiently adverse to restrict the activity of other pollinating insects. The honey bee has been considered a less efficient pollinator than the bumble bee since it lacks a proboscis of sufficient length to reach the nectar easily and is a more intermittent visitor with a slower rate of working.

Pammel and Kennoyer (14) obtained results in Iowa indicating that, while honey bees might be as efficient as bumble bees in the pollination of red clover during dry summers, they were less reliable in cool wet ones. Similar observations have been reported by Westgate, *et al.* (24), Williams (29), and Wexelsen (25). Megee and Kelty (9) reported that bumble bees might be found working at a temperature of 60°F when honey bees were inactive. Richmond (20) and Plath (18) observed that bumble bees might be found active at sunrise and even after sunset. Observations that have been made on the rate of working of bumble bees or honey bees by Pammel and King (13), Westgate, *et al.* (24), Williams (29), Pedersen (16), Wexelsen (25), and Dunham (4) all indicate that the bumble bee is the more rapid worker.

Several investigators have noted the irregularity of the honey bee as a visitor to red clover. Stapel (22) and Parker (15) have suggested that honey bees visiting red clover mainly for the collection of pollen might not find it a satisfactory source of such material throughout the whole of the blooming period. Wexelsen (25) pointed out that the efficiency of the honey bee as a pollinator of red clover was reduced by its habit of seeking out the older heads some of which were by that time incapable of fertilization. Pammel and Kennoyer (14), Pedersen (16), and Butler (3) have expressed the view that honey bees might be attracted to red clover only at certain times when conditions were such as to increase the height of the nectar in the carolla tube or make it more accessible or acceptable to them in some way.

Williams (29) has referred to the isolation in Europe of strains of red clover having short corollas which were freely visited by honey bees. However, when such strains were compared with domestic strains in North America, neither Wilsie and Gilbert (31) nor Armstrong and Jamieson (2) found them more attractive to honey bees or notably superior in seed setting capacity. The possibility that the short-corolla character of certain inbred lines might be simply a manifestation of reduction in vigour has been pointed out by Wexelsen (26). Akerberg (1) has suggested that with such variation in corolla tube length as exists in Norrland strains, the continued pollination of red clover by honeybees might lead to the development of short-corolla strains by natural selection. The development of short-corolla strains is still considered among worthy objectives in red clover breeding by Pohjakallio (19) and Wexelsen (26).

On account of a shorter corolla tube length, Pedersen (16) considered that the chances of a honey bee reaching the nectar was seven times as great in late- as in early-flowering red clover. Pammel and Kennoyer (14), however, found close agreement between the corolla-tube length of florets from the aftermath as compared with those of the first growth which had bloomed earlier in the summer.

Westgate, *et al.* (24) mentioned an opinion prevalent among some investigators and bee men that some strains of the Italian race of honey bees were able to obtain some nectar from red clover. Moreover, Stapel (22) found that Italian honey bees visited red clover more willingly than Danish bees. He assumed that the difference in visiting was due to the slightly longer proboscis of the Italian bee. However, Richmond (20), after reviewing the observations of several investigators on the

tongue length of the honey bee, considered it as open to question if there was really any genuine long-tongued race of honey bees. He concluded that the length of the corolla tube had no bearing upon the pollination of red clover by these insects.

Owing to a peculiar habit of obtaining nectar, at times, from slits which they make at the base of the corolla tube, certain species of bumble bees have been considered as having a negative influence upon pollination by Williams (29), Pedersen (16), Wexelsen (25), and Stapel (22). These so-called robber bees not only fail to effect pollination themselves but encourage honey bees to obtain nectar through the slits which they make, so that the honey bees have likewise a negative influence upon pollination. As Pedersen (16) has shown, the larger the number of robber and negative bumble bees, the larger is the number of negative honey bees. He has also shown that the percentage of these negative bees varied greatly, even from field to field. In general he found the percentage of negative bees higher in early than in late red clover, but later he (17) expressed the view that there was no fixed relation between the number of such bees and the time of flowering.

Williams (29) has pointed out that for satisfactory seed production, red clover should be in bloom at a time when worker bumble bees are flying in sufficient numbers to pollinate the crop adequately. In Wales, the number of bumble bees did not increase rapidly until the last week in July and only reached a maximum in August long after the first growth was in bloom. This indicated a need for cutting the first growth so as to postpone the blooming period of the seed crop until a more favorable time. The necessity of similar cutting treatments in Scandinavian Europe has been pointed out by Wexelsen and Skare (27) and Akerberg (1). In America, the value of such cutting treatments for the increase of seed production has been demonstrated by Willard, *et al.* (28) and Megee, *et al.* (10). The possible selective influence of such treatments upon the time of flowering of a strain has been pointed out by Hellbo (6).

Stapel (22) and Pedersen (16) have observed that in Denmark honey bees were inclined to visit late-flowering strains of red clover more freely than those of the early type. In this connection, Stapel (22) calculated that honey bees would be responsible for as much as 60% of the pollination work on the late as compared with 25% on the early type.

Among other insect visitors to red clover blooms, Megee and Kelty (9) have mentioned small wild bees, Folsom (5) has reported two species of burrowing bees, and Robertson (21) has listed 13 species of Lepidoptera.

SEEDS PER HEAD

Westgate, *et al.* (24) from counts of seed per head collected under ordinary field conditions in Iowa in 1911 and 1912 obtained about 40 seeds per head. Similar results were obtained by Williams (29) under field conditions in Wales, but this was during the wet summer of 1924, unfavorable to bee activity. Hollowell (7) pointed out that an average of 25 seeds per head was considered sufficient to assure a fair seed crop under field conditions. Wexelsen (25) counted the number of seeds per head in a series of heads and obtained an average of 52.5 seeds per head.

In a previous paper Wexelsen and Skare (27) had presented results of counts made on number of seeds per head in heads which were in bloom over different periods during the summers of 1932 and 1933. In order to get 10-head samples that had been in bloom over different periods, they collected samples at four degrees of ripeness, *viz.*, blackish-brown heads (ripest), dark-brown heads, brown heads with green sepals, and light-brown heads with green sepals. It was found

that the ripest heads which had bloomed the earliest had the poorest set of seed. In 1933 these same authors had marked out and kept under observation four drill-sown plots of red clover. On these plots heads were marked at the following stages of bloom: All florets opened, one half the florets opened, some florets opened, and no florets opened. From each of these plots an average of 70 heads were harvested and the seeds per head counted. For the stages mentioned the seeds per head were, respectively, 46.6, 51.4, 57.1, and 65.3, the seed setting being progressively superior with the later opening of the florets. In the same year, another seed setting experiment was carried out with 12 individual plants of the Toten strain of red clover which began flowering at dates ranging from June 26 to July 8. The seeds per head from these plants were found to be progressively more numerous with the later flowering plants.

METHODS

Over a 5-year period, 1938 to 1942, inclusive, the seed setting in a strain of early, double-cut red clover was determined by counting the seeds per head from random samples of heads which had been in bloom over different periods during the summer in small replicated plots approximately 5 links × 5 links. The period of bloom for each head was indicated by means of a pyralin tag affixed to the stem just underneath the head as the florets commenced to open. Tagging was carried out at approximately 2-day intervals during the entire blooming period of the crop and each tag bore the number of the interval on which it was used. The natural blooming period of the crop was greatly extended, as shown in Table 1, by the use of cutting treatments which postponed the bloom on different plots until successively later periods. The cutting treatments were randomized within six blocks and for each treatment at least 60 heads, 10 from each plot, were tagged at each of the various intervals. Considerable bloom was maintained on the area surrounding the plots by cutting a part of the crop in early June.

Although much the same procedure was followed throughout the entire study, experience during the first year indicated the importance of using several cutting treatments in order to obtain a more even distribution of bloom throughout the summer. Provision was therefore made for increasing the number of these cutting treatments in later years.

As the heads ripened they were carefully collected and threshed by hand. All the seeds were counted irrespective of whether they were well-formed, shrunken, or injured by insect attack.

In order to determine if there was any important influence of number of florets per head upon seed set per head, counts were made of the florets per head in 25-head samples collected at random from three different treatments at weekly intervals during their period of bloom.

The Entomology Department, Macdonald College, cooperated in this study from 1939 onwards by collecting data on the species and numbers of pollinating insect visitors to the experimental area, as already reported by Morrison (11).

RESULTS AND DISCUSSION

The average number of seeds from red clover heads tagged at the beginning of bloom throughout the flowering period of the crop during the years 1938 to 1942, inclusive, is shown in Table 1. In general, a low set of seed has been obtained with the uncut treatment, or first growth, as compared with the aftermaths following cuttings made at

weekly intervals during the month of June. However, there was an exception to this in 1939 when a very poor set of seed was obtained with the aftermath following the June 1 cutting. Of the different aftermath crops, the best seed setting has been obtained with the cutting treatments made in early or mid-June, but good seed setting was obtained with the June 29 cutting in 1941.

The trend of seed setting during the blooming period of the various cutting treatments is shown in Table 1, but is perhaps more easily followed from the graphical representation of a part of the data in Fig. 1. Here, a moving average of seeds per head for three tagging dates has been used to smooth out the graph, the average for the three dates being credited to the middle tagging date in each case. The trend of seeds per head for the uncut treatment appears mainly downward until it reaches a low figure toward the end of the blooming period for this treatment about the first of July. After this time, there is an indication that the seed setting might be expected to improve as shown in the graph for 1940 when the period of bloom for the uncut treatment was prolonged well into July. The trend during the blooming period of the aftermath following the June 1 cutting inclines upward and that following the June 22 cutting inclines downward, but there is an exception to this in 1939 when, as mentioned above, the seed setting of the aftermath following the June 1 cutting was quite poor. The best period for seed-setting, as shown in Table 1, covers the last two weeks of July and the first week of August. This period coincides fairly well with the period of bloom for the after-

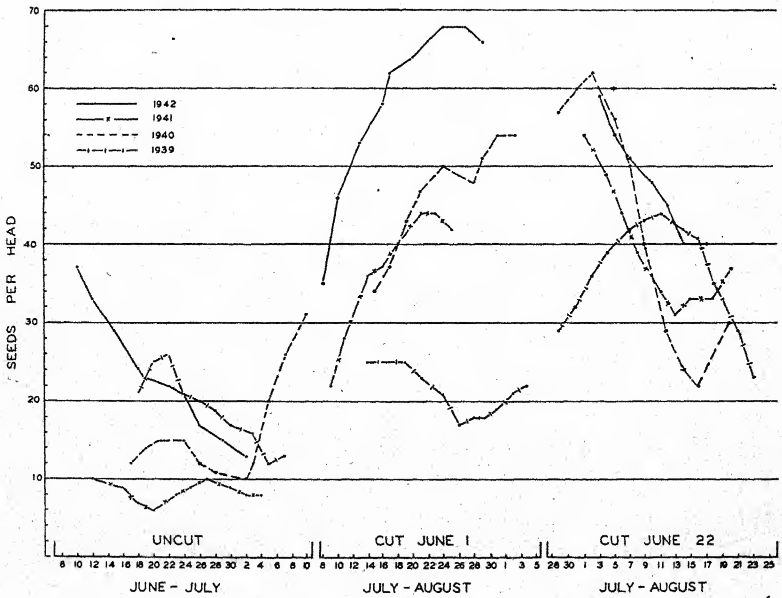


FIG. 1.—Seeds per head based upon a moving average from heads commencing to bloom at three successive dates during the seasons of 1939 to 1942, inclusive.

TABLE 1.—*Average number of seeds per head from red clover heads tagged at beginning of bloom on plots receiving different cutting treatments, and bee visitors recorded on tagging dates, 1938–42.**

	Tag No.																																			Mean
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	
1938																																				
	June								July													August														
	13	15	18	20	22	24	27	29	2	4	7	9	11	13	16	18	20	22	25	27	29	1	3	5	8											
Seeds per head:																																				
Uncut	40	29	12	16	17	18	15	14	7	11	17	11	10	—	—	—	—	—	—	—	—	—	—	—	—											16
Cut June 1	—	—	—	—	—	—	—	—	—	—	—	—	—	54	60	56	66	58	49	68	48	45	38	44	42											55
1939																																				
	June								July														August													
	15	18	20	22	24	26	28	30	3	5	7	10	12	14	17	19	21	24	26	28	29	31	2	4	7	9	11	14	16	18	21	23	25			
Bumblebees	—	—	—	—	6	7	5	—	9	3	2	3	3	2	1	2	10	6	9	4	—	2	10	10	5	0	14	3	5	10	2	5				
Seeds per head:																																				
Uncut	20	21	23	31	25	18	17	22	12	13	12	14	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—			19
Cut June 1	—	—	—	—	—	—	—	—	—	—	—	—	27	25	24	25	26	17	19	15	19	20	19	25	22	—	—	—	—	—	—	—	—			22
Cut June 22	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	30	26	32	38	39	39	49	41	43	43	38	25	25	19			35
1940																																				
	June							July															August													
	15	17	19	21	24	26	28	2	3	5	7	10	12	15	17	19	21	24	26	28	29	31	2	5	7	9	12	14	16	20	21	23	26	28	30	
Honeybees	—	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	5	7	4	—	1	2	4	4	7	10	5	2	7	0	0	0	0	—	—	
Bumblebees	—	2	3	1	2	0	2	1	0	1	0	0	17	0	5	4	4	14	9	—	9	17	27	11	32	25	14	25	15	1	14	11	22	—	—	
Seeds per head:																																				
Uncut	10	9	16	17	13	14	10	8	13	16	30	31	32	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	17
Cut June 1	—	—	—	—	—	—	—	—	—	—	—	—	32	30	40	42	47	51	51	44	50	59	54	50	—	—	—	—	—	—	—	—	—	—	—	46
Cut June 8	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	38	37	43	53	54	56	52	60	51	40	—	—	—	—	—	—	—	—	—	—	48
Cut June 22	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	48	58	66	57	62	50	38	32	17	23	25	43	—	—	—	—	43
Cut June 29	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	44	35	28	15	21	31	36	35	34	36	39	32
1941																																				
	June									July													August													
	11	13	16	18	20	23	25	27	30	2	4	7	9	11	14	16	18	21	23	25	28	30	1	4	6	8	11	13	15	18	20	22	25	27	29	
Honeybees	—	0	0	1	0	0	0	—	0	0	0	2	0	0	3	1	3	2	6	0	—	1	0	0	0	0	0	0	0	0	0	0	0	0	0	
Bumblebees	—	0	0	5	2	1	1	—	1	2	0	0	0	0	10	30	21	25	44	30	—	30	29	32	20	15	15	9	10	12	4	0	14	0	5	
Seeds per head:																																				
Uncut	8	11	10	6	6	7	10	10	9	7	9	9	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	8
Cut June 1	—	—	—	—	—	—	—	—	—	—	—	17	15	33	35	39	38	42	51	38	37	—	—	—	—	—	—	—	—	—	—	—	—	—	—	35
Cut June 8	—	—	—	—	—	—	—	—	—	—	—	—	—	—	31	31	36	53	52	48	48	46	51	52	—	—	—	—	—	—	—	—	—	—	—	45
Cut June 15	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	56	48	48	50	51	57	47	44	41	36	44	—	—	—	—	—	—	—	46
Cut June 22	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	58	52	51	43	38	36	28	28	42	30	39	—	—	—	—	42
Cut June 29	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	53	50	42	50	46	40	45	57	39	—	—	—	47
1942																																				
	June										July													August												
	8	10	12	15	18	19	22	24	26	29	2	3	6	8	10	13	16	17	20	22	24	27	29	1	3	5	7	10	12	14	17	19	21	24	26	
Honeybees	3	5	5	0	0	0	0	0	0	0	0	0	0	0	3	0	0	42	40	77	64	52	8	2	1	1	0	—	0	2	0	1	0	—	0	
Bumblebees	15	13	16	8	9	5	6	7	7	2	1	0	0	3	1	5	5	59	26	57	70	51	49	84	88	76	101	—	83	91	48	46	38	—	43	
Seeds per head:																																				
Uncut	39	37	35	28	23	20	25	21	17	14	14	11	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	23
Cut June 1	—	—	—	—	—	—	—	—	—	—	—	—	16	42	46	50	62	63	61	68	68	68	69	61	—	—	—	—	—	—	—	—	—	—	—	56
Cut June 8	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	52	57	63	76	66	68	61	61	59	59	—	—	—	—	—	—	—	—	—	62
Cut June 15	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	42	63	64	67	61	55	62	61	48	45	49	—	—	—	—	—	—	56
Cut June 22	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	65	58	55	48	49	46	39	36	44	—	—	—	49
Cut June 29	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	58	51	43	46	47	43	40	43	33	45

*A blank in bee data indicates no observation on account of rainy weather.

math following the June 8 cutting, but also includes a portion of the blooming period of aftermaths following cuttings made on July 1, 15, and 22, respectively.

Observations covering the years 1939 to 1942, inclusive, of the number of bumble bee and honey bee visitors to the experimental area on the various tagging dates are also recorded in Table 1, and the trend of bumble bee numbers during the summer, based upon a moving average, has been shown graphically by Morrison (11). The seasonal and yearly trends for seeds per head resemble fairly closely the seasonal and yearly trends for numbers of bumble bees. This close relation would seem to justify the significance attached to these insects in connection with the fertilization of red clover by many investigators. The seasonal trend in bumble bee numbers, as pointed out by Morrison (11), is characterized by a small peak in early or mid-June when the queens are foraging to stock their nests. This is followed by a very low trough in late June and early July during the incubation of the early brood and by a large peak in late July or early August when workers are flying in large numbers. Bumble bee numbers also appear to vary greatly from year to year with some suggestion of a cyclic trend.

The smaller number of honey bees recorded would seem to indicate that they were of lesser significance than the bumble bees in the pollination of this crop. They were only sufficiently numerous to be of any importance in pollination during a short period in late July 1942. The reason for such occasional visits of large numbers of honey bees to red clover has been the subject of much speculation. Some writers have stressed the importance of the length of the corolla tube in this connection. Measurements made upon the same strain of red clover as used in these experiments and growing in nearby plots in 1942 showed a decrease of 0.9 mm between the length of corolla tubes in 25-head samples collected from the first growth on June 15 and the aftermath on July 27. While this difference is statistically significant, it is very doubtful if such a small decrease could have made the aftermath crop more attractive to honey bees during the above-mentioned period. The scarcity of other nectar or pollen sources at the time would seem a more logical explanation. However, the apparent preference of nectar-collecting honey bees for the older florets, some of which are already dying back from the tips, may arise from a shortening of the corolla associated with this condition.

Weather conditions during the period of bloom are known to affect the condition of the flowers and the activity of pollinating insects from day to day. However, so long as the dry or rainy spells of weather are not too protracted, their influence on the seed setting of red clover may be of little significance. The effect of minor, day-to-day variations in weather conditions is partially offset by the fact that heads may remain in bloom for a week or 10 days, depending on weather conditions. Even during protracted spells of weather there are compensating effects. Long spells of cloudy, rainy weather, although holding up pollinating activities of insects, tend to prolong the period over which the crop remains in bloom, while long spells of clear, dry weather, although favorable for insect activity, tend to curtail the period of bloom.

The possibility that a wide seasonal variation in number of florets per head might influence the seasonal variation in number of seeds per head has not been overlooked in this study. Counts of florets per head in 25-head random samples collected at weekly intervals during the blooming period of the first growth and aftermath crops are shown in Table 2. The range in number of florets between the weekly samples is comparatively small as compared with the wide range within these samples. A fairly well-defined downward trend is shown with samples collected at successively later weekly intervals from the uncut treatment, but not for the aftermaths following cutting treatments. From the data at hand it would seem that, even under the most favorable conditions during this study, the florets setting seed did not exceed 75% of those available for pollination. The number of florets per head was, therefore, a rather minor factor in determ-

TABLE 2.—*Florets per head in random samples of 25 heads collected at weekly intervals from plots receiving three different cutting treatments, 1939–42.*

	Uncut		Cut June 1		Cut June 22	
	Mean	Range	Mean	Range	Mean	Range
			1939			
1st week	115	82–189	96	67–137	98	73–129
2nd week	117	74–162	97	57–145	95	63–137
3rd week	107	85–138	96	53–138	94	65–134
4th week	92	60–115	—	—	—	—
Mean	108		96		96	
			1940			
1st week	124	98–173	103	60–167	111	65–148
2nd week	117	89–157	121	73–197	123	85–170
3rd week	101	65–147	103	62–151	112	57–156
4th week	85	56–122	—	—	—	—
Mean	107		109		115	
			1941			
1st week	121	96–169	102	47–143	110	50–151
2nd week	95	69–146	107	69–146	109	62–158
3rd week	88	61–123	96	63–128	95	62–140
4th week	70	41– 98	—	—	—	—
Mean	94		102		105	
			1942			
1st week	115	78–148	87	51–132	114	74–149
2nd week	113	73–157	119	87–157	111	89–171
3rd week	102	72–150	116	80–160	98	62–132
4th year	86	57–131	—	—	—	—
Mean	104		107		108	
			Mean			
1939–42	103		103		106	

ining the number of seeds per head as compared with pollinating agents such as the bumble bee.

Damage to flower heads by thrips and other insects during this study was never serious and was not restricted to any particular period or crop treatment.

SUMMARY AND CONCLUSIONS

A 5-year study of seed setting based upon number of seeds per head was carried out with a strain of early, double-cut red clover. The natural blooming period of the crop was greatly extended by a series of cutting treatments made at weekly intervals during June, which postponed the time of blooming of their respective aftermaths until successively later periods of the summer.

Tagging of heads was carried out at approximately 2-days intervals at each of which at least 60 heads were tagged on plots in bloom as a result of the various cutting treatments. When the seeds ripened they were threshed out by hand and counted.

The seasonal trend of seeds per head, although varying somewhat from year to year, showed rather low seed setting in the first growth, gradually declining to a marked low level during late June and early July then rising to a maximum in late July and early August.

The seasonal and yearly trends of seeds per head agreed fairly closely with those of numbers of bumble bees for the same periods reported earlier.

Under the conditions of this study it was concluded that the number of bumble bee visitors was a much more important factor in seed setting than number of honey bee visitors or number of florets per head. Aftermath crops of red clover brought into full bloom during late July or early August have a much better chance of receiving satisfactory pollination than the first growth blooming earlier in the season or aftermath crops brought into full bloom at a later date.

LITERATURE CITED

1. AKERBERG, E. The fertilization of red clover. Svensk. Frötidn., 10:143–146. 1941. (Abs. No. 96, Herbage Abs., 13. 1943.)
2. ARMSTRONG, J. M., and JAMIESON, C. A. Cross-pollination of red clover by honey bees. Sci. Agr., 20:574–585. 1940.
3. BUTLER, C. G. A study of the frequency with which honey bees visit red clover (*Trifolium pratense*) together with an examination of the environmental conditions. Ann. Appl. Biol., 28:125–134. 1941.
4. DUNHAM, W. E. Collecting red clover pollen by honey bees. Jour. Econ. Ent., 32:668–670. 1939.
5. FOLSOM, JUSTUS. Pollination of red clover by *Tetralonia* and *Melissodes*. Ann. Ent. Soc. Amer., 15:181–184. 1922.
6. HELLBO, E. Genuineness of type in red clover. Herbage Reviews, 8:139–142. 1940.
7. HOLLOWELL, E. A. Influence of atmospheric and soil moisture upon seed setting in red clover. Jour. Agr. Res., 39:229–247. 1929.
8. MARTIN, J. N. The physiology of the pollen of *Trifolium pratense*. Bot. Gaz., 56:112–126. 1913.
9. MEGEE, C. R., and KELTY, R. H. The influence of bees upon clover and alfalfa seed production. Mich. Agr. Exp. Sta. Quart. Bul., 14:271–277. 1932.
10. ———, FRAKES, M. G., and LARSEN, I. T. The influence of clipping treatment and rolling on the yield of clover seed. Jour. Amer. Soc. Agron., 34:841–843. 1942.

11. MORRISON, F. O. Observations on the number and species of bumble bees visiting red clover. 73rd Ann. Rpt. Ent. Soc. Ont., 1942:16–20. 1943.
12. PAMMEL, EDNA C., and CLARK, CLARISSA. Studies on variation of red clover. Proc. Iowa Acad. Sci., 18:47–54. 1911.
13. PAMMEL, L. H., and KIBG, CHARLOTTE M. Pollination of red clover. Proc. Iowa Acad. Sci., 18:35–45. 1911.
14. ———, and KENNOYER, L. A. Additional notes on the pollination of red clover. Proc. Iowa Acad. Sci., 24:357–365. 1917.
15. PARKER, R. L. The collection and utilization of pollen by the honey bee. Cornell Univ. Agr. Exp. Sta. Mem. 98. 1926.
16. PEDERSEN, AXEL. Pollination of red clover and attack of red clover by weevils (*Apion sp.*). Nordisk. Jordbrugsforskn., 17:498–507. 1935. (Translation No. 18, Imp. Bur. Pastures and Forage Crops, Aberystwyth.)
17. ———. Flowering, pollination and attack of *Apion sp.* in early red clover for seed. Tidsskr. Planteavl., 45:525–550. 1941. (Abs. No. 1169, Herb. Abs., 12. 1942.)
18. PLATH, O. E. Bumblebees and their ways. New York: The Macmillan Co. 1934.
19. POHJAKALLIO, ONNI. Red clover breeding in Finland. Imp. Agr. Bureaux Joint Pub. No. 3:115–120. 1940.
20. RICHMOND, R. G. Red clover pollination by honeybees, in Colorado. Colo. Agr. Exp. Sta. Bul. 391. 1932.
21. ROBERTSON, C. Flowers and insects. Bot. Gaz., 17:177–178. 1892.
22. STAPEL, C. The pollination of red clover with special reference to the significance of honey bees. Nordisk. Jordbrugsforskn., 17:508–517. 1935. (Translation No. 17, Imp. Bur. Pastures and Forage Crops.)
23. SYLVEN, NILS. Seed setting of red clover. Nordisk. Jordbrugsforskn., 17:472–477. 1935. (Translation No. 16, Imp. Bur. Pastures and Forage Crops.)
24. WESTGATE, J. M., and COE, H. S., in collaboration with Wiancko, A. T., Robbins, F. E., Hughes, H. D., Pammel, L. H., and Martin, J. N. U.S.D.A. Bul. 289. 1915.
25. WEXELSEN, H. Investigations on the pollination of red clover. Nordisk. Jordbrugsforskn., 17:478–488. 1935. (Translation No. 15, Imp. Bur. Pastures and Forage Crops.)
26. ———. Selection and inbreeding in red clover and timothy. Imp. Agr. Bureaux Joint Pub. No. 3:93–114. 1940.
27. ——— and SKARE, S. Flowering and pollination of red clover. Tidsskr. Norske Landbr., 41:63–89. 1934. (Translation No. 288, Imp. Bur. Pastures and Forage Crops.)
28. WILLARD, C. J., CUTLER, J. S., and MCLAUGHLIN, J. B. Ohio Agr. Exp. Sta. Bimonthly, Bul., 19:39–43. 1934.
29. WILLIAMS, R. D. Studies concerning the pollination, fertilization and breeding of red clover. Welsh Plant Breeding Sta. Bul. Ser. H., No. 4. 1925.
30. ———. Some of the factors influencing the yield and quality of red clover seeds. Welsh Plant Breeding Sta. Bul. Ser. H., No. 11:60–91. 1930.
31. WILSIE, C. P., and GILBERT, N. W. Preliminary results on seed setting in red clover strains. Jour. Amer. Soc. Agron., 32:231–234. 1940.

NOTES

THE RELATION OF GRAZING TO ESTABLISHMENT AND VIGOR OF CRESTED WHEATGRASS

THE costs of protecting newly seeded lands from grazing have hindered the extension of artificial reseeding to many western range lands. Generally, results from investigations and experience in handling newly reseeded range justifies the general principle which states that complete protection from grazing should be given the seeded area during the first year. However, exception to this general principle has been reported and this paper presents the results of grazing on the establishment and vigor of crested wheatgrass seeded at several localities in southeastern Idaho which further strengthen the belief that under certain conditions of soil and weather, moderate grazing may be practiced during the first year.

One set of measurements was secured from a spring-fall range north of Dubois, Idaho, which previously supported a dense stand of sagebrush (*Artemisia tridentata*) and was accidentally burned during 1937. That fall a reseeding site was selected on the burned area and drilled to crested wheatgrass at a rate of 10 pounds per acre with rows spaced 6 inches apart. Most of the seeded area was fenced to protect it from grazing, but one part was left unprotected.

Seedlings in the protected area became well established and produced some seed in 1938. Good forage and seed crops were produced in 1939 and again in 1940. Annual weeds were abundant in both fenced and unfenced areas the first year but were later crowded out by the crested wheatgrass. Heavy grazing for more than a month during the early spring and for a similar period in fall kept the seeded plants outside of the fence eaten to within 1 inch of the ground during 1938 and 1939. In the fall of 1939 the protected area was enlarged to include the seeded area which had been grazed for 2 years.

The effects of grazing were determined by plant counts, by measurements of plant height, and from yield on 13 samples on the area which had been grazed for 2 years before being protected (area A) and by a similar number of samples on the area totally protected for 4 years (area B). Plant counts were made in 1940, and average plant height and green herbage weights were obtained in 1940 and 1941.

In 1940, the first year of protection for area A, the herbage production and height of plants were significantly greater on B than on A (Table 1). These differences, together with the larger grass clumps and the longer heads of the protected plants, were readily apparent. Under protection the plants on A increased rapidly in vigor and after 2 years of protection against spring grazing (1941) were equal to the fully protected plants except they were still not quite so tall. There was no significant difference in plant numbers between the two areas.

New seedlings on B were abundant both in 1940 and 1941, but the complete stand of older plants doubtless precluded their successful establishment. No new seedlings were found on A in 1940, but in 1941 a few were present.

While grazing following reseeding did not affect the number of plants in this test, it would be dangerous to assume that similar

favorable results would follow grazing of all reseeded areas. Careful evaluation should be made of all the known factors responsible for plant establishment. Factors which apparently favored plant establishment on these test areas in spite of grazing are as follows: (1) The land is level with a firm surface that is seldom cut up under trampling. (2) Precipitation was above average during the first season. (3) Seed was covered ½ inch deep in the bottom of 1-inch drill furrows, the deep seeding resulting in less chance that seedlings would be pulled out by grazing or trampling than if seeding had been done by shallow drilling. (4) Some plant growth occurs after spring grazing on this area and plants were thus given some opportunity to recuperate.

TABLE 1.—*Herbage weight, plant height, and plant counts of 3- and 4-year-old crested wheatgrass plants on a protected area and on an area grazed 2 years before being protected in southeastern Idaho.*

Plant counts and measurements	Plants, 3-yr-old (1940 data)			Plants, 4-yr-old (1941 data)		
	A, grazed 2 yrs.; protected 1 yr.*	B, protected 3 yrs.	Standard error of mean difference (protected minus grazed)	A, grazed 2 yrs.; protected 2 yrs.*	B, protected 4 yrs.	Standard error of mean difference (protected minus grazed)
Herbage per linear foot of drill row, grams green weight.......	25.1	33.3	2.16	29.1	31.1	2.17
Average height, inches	19.6	26.9	0.49	25.5	27.1	0.64
No. plants per linear foot of drill row.....	3.02	2.48	0.26	Not counted	Not counted	Not counted

*Opened to grazing during first and second growing seasons and protected during the third and fourth.

In another study at the same location, crested wheatgrass was drilled inside and outside of an enclosure each year from 1939 to 1942, inclusive. Counts show that the unprotected plants which were grazed spring and fall to within 1 inch ofthe ground level were equal in number to the totally protected plants. Crested wheatgrass drilled in 1938 inside and outside another enclosure on a dry site near Dubois produced a good stand. Although plants outside the fence have been grazed by horses to within 1 or 2 inches of the ground every spring, summer, and fall since planting, there is no difference in number of plants on protected and unprotected areas. Vigor of the unprotected plants is very low, however. First- and second-year results from still another study designed to show the effects of grazing upon newly drilled species when given various degrees of grazing protection indicate no difference in plant numbers on protected and moderately grazed plots.

Results from these studies and from many observations on plantings made by stockmen throughout southern Idaho indicate that full

stands of crested wheatgrass may be secured under grazing, although vigor of the plants is likely to be low. To be able to graze seeded range land during the first year of establishment without injury to the stand is of sufficient economic importance to call for further investigation to determine what the conditions are that would make this possible.—A. C. HULL, JR., *Intermountain Forest and Range Experiment Station, Forest Service, U. S. Dept. of Agriculture, Ogden, Utah.*

AMOUNT OF NATURAL OUT-CROSSING IN THE CASTOR OIL PLANT

RECENT seed-increase programs and renewed breeding activities with the castor oil plant have emphasized the need for information on the amount of natural out-crossing which occurs in this species. Data on this point were obtained by growing plants homozygous for a simple recessive gene among plants homozygous for the dominant allelomorph and observing, in the resulting progenies, the percentages of plants that carried the dominant gene.

The recessive character used was "spineless," or the absence of spines on the capsules. A strain bearing this character was developed at the Illinois Agricultural Experiment Station by successive self-fertilizations of a spineless plant found in a plot of the U. S. 4 variety. Harland,[1] Peat,[2] and Patwardhan[3] reported that the presence of spines in similar strains was due to a single factor *S*, which lacks dominance over *s*. The F_2 segregations for the spineless character in the strain under consideration are given in Table 1, and show that the presence of spines in this material is also governed by a single gene. However, the observations by Harland, Peat, and Patwardhan that all heterozygous genotypes were easily distinguishable from *SS* genotypes by observation were not verified in these populations since

TABLE 1.—*F_2 segregations of the spined-spineless character, showing agreement to a 3:1 ratio.*

Progeny	Number of plants		χ^2	P
	Spined	Spineless		
A	25	5	1.111	0.20–0.30
B	58	13	1.695	0.10–0.20
C	61	28	1.981	0.10–0.20
D	43	12	0.297	0.50–0.70
E	25	9	0.039	0.80–0.90
F	25	2	4.457	0.02–0.05
G	25	10	0.238	0.50–0.70
Total			9.818	0.10–0.20

[1]HARLAND, S. C. The genetics of *Ricinus communis* L. Bibliographia Genetica, 4:171–178. 1928.

[2]PEAT, J. E. Genetic studies in *Ricinus communis* L. Jour. Genetics, 19:373–389. 1928.

[3]PATWARDHAN, G. B. A preliminary note on inheritance in castors. Jour. Ind. Bot. Soc., 10(2):100–109. 1931.

many gradations in number of spines were observed both between and within plants.

While at the Illinois Station the writer grew several spineless plants in a 42-inch spaced planting where each was completely surrounded by plants which were homozygous for the spined character. The open-pollinated seeds harvested from the spineless plants were planted at the Plant Industry Station, Beltsville, Md. Progenies from seven such plants were grown and the numbers of plants in each that were spined and spineless are given in Table 2. These data indicate the amount of natural out-crossing which occurred in the seven plants studied, expressed as percentages of hybrid plants in their progenies. The average of 36% is much greater than White's[4] estimation of "probably not more than 5%".

TABLE 2.—*Spineless and spined frequencies in progenies of spineless plants permitted to out-cross with spined plants.*

Parent plant number	Number of plants			Percentage of out-crossing
	Spineless	Spined	Total	
1	57	46	103	45
2	37	20	57	35
3	37	19	56	34
4	28	24	52	46
5	19	22	41	54
6	22	5	27	19
7	20	5	25	20
Average				36

The necessity of uniform seed size and shape for efficient mechanical hulling and the relatively large amount of natural out-crossing in this species requires complete isolation of seed-increase fields from off-type plants.—W. E. DOMINGO, *Division of Drug and Related Plants, Bureau of Plant Industry, Soils, and Agricultural Engineering, Agricultural Research Administration, U. S. Dept. of Agriculture, Beltsville, Md.*

[4]WHITE, ORLAND E. Breeding new castor beans. Jour. Hered., 9:195–200. 1918.

ATYPIC DWARFING IN SORGO

THIS is a preliminary report on the occurrence of a peculiar type of dwarfing in strains of sorgo. A range of dwarf types, i. e., "degrees of dwarfing", was found; of these, however, the most unusual ones were in an inbred line, No. 3049–9, of Straightneck, M. N.[1] 51, in 1943. Plant 3049–9 was one of 20 selections made from a single plot in 1942 and was one of seven finally selected for planting because of its outstanding appearance and juice analysis. It was as good or better than average in height and stalk diameter, and had a juice analysis of 19.4 degrees Brix, the highest in the plot. The average

[1]M. N. refers to accession numbers used at U. S. Sugar Plant Field Station, Meridian, Miss.

and the range in degrees Brix of the 20 plants in plot 3049 were 14.7 and 10.9 to 19.4, respectively.

The contrast in growth 50 days after planting (April 16, 1943) between the dwarf inbred line and a "normal" line is illustrated in Fig. 1. Fig. 2 is a "close-up" of a typical dwarf plant (plant No. 1 in center row of Fig. 1). The leaves of the dwarf plants of inbred 3049-9 were thick, more or less leathery, crinkled and somewhat rolled, and usually showed marginal discoloration (red, purple, brown). The last leaf produced was very narrow, often in the form of a "coiled string", and upon dissection, no clear line of demarcation between leaf and stem tissue was found. The stalk was stiff and very short, never attaining a height of more than a few inches to 1 foot. No panicles were produced from this planting. On June 30, when other inbreds of this variety were heading, typical dwarf plants were examined by longitudinally splitting the stems. The entire growing point was decayed

FIG. 1.—Inbred line 3049-9 (center, dwarfed) and a "normal" line of Straightneck, M. N. 51, 50 days after planting.

TABLE 1.—*Total number of plants, number of plants heading, number of seeds produced, and seed weights in two inbred lines and a check lot of Straightneck, M. N. 51.**

Type	Number of plants		Number of seeds			Seed weight, grams			Weight per 1,000 seeds, grams
	Total	Heading	Total	Range	Average	Total	Range	Average	
3049-9	39	6	1,374	120-455	229†	16.86	1.45-5.65	2.81†	12.27
49-2	35	10	1,079	0-385	108‡	10.80	0.00-4.77	1.08‡	10.01
Check	40	40	—	—	—	70.30	—	1.76	12.07

*45 seeds of each type planted June 4.
†Average of 6 plants producing heads.
‡Average of 10 plants producing heads.

and on August 5 (average maturity date for the variety in 1943) the entire internal tissue of the peduncle was rotted and decayed. In most cases, this rotting did not extend below the peduncle.

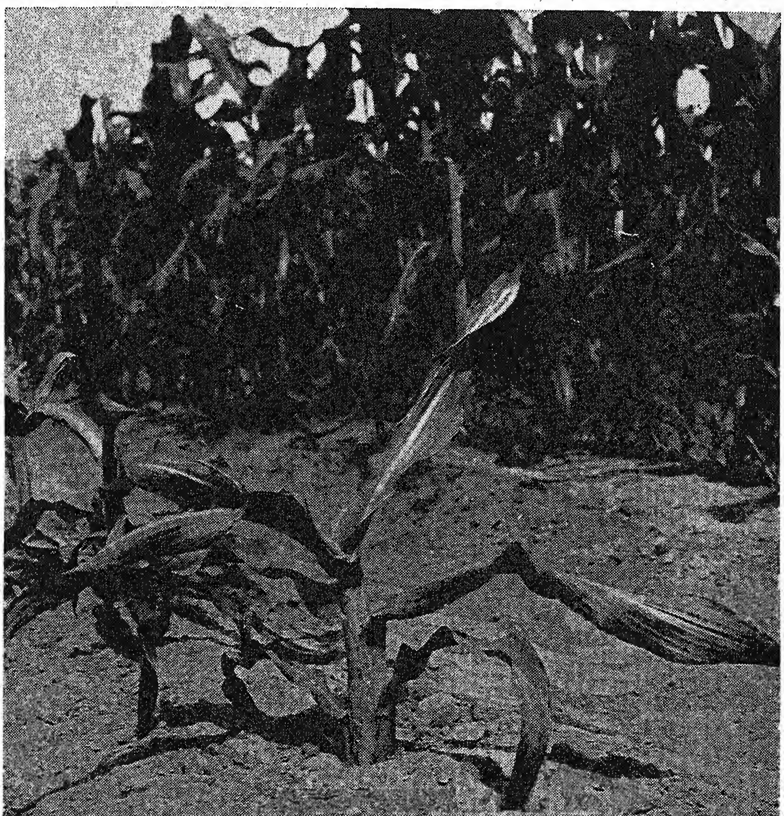


FIG. 2.—A typical dwarf plant of inbred line 3049–9 of Straightneck, M. N. 51, 50 days after planting.

A second planting was made on May 25, 1943. Although the plants attained a somewhat greater average height than those in the April 16 planting, again no panicles were produced.

On June 4, a third planting was made which consisted of 45 seeds each of two inbred lines, 3049–9 and 49–2, and a check lot of Straightneck, M. N. 51. Plant 49–2 was one of 18 selected in 1942 and one of two finally selected for planting in 1943 because of high juice quality (degrees Brix 19.0). The average and the range for the 18 plants were 13.7 and 9.4 to 19.0, respectively. Line 49–2 produced "degrees of dwarfing" and a few panicles in the April 16 and May 25 plantings. Emergence was good, ranging from 78 to 89%. Data on total number of plants, number of plants heading, number of seeds produced, and

seed weights are presented in Table 1. In this planting, the dwarf plants attained a relatively greater height, in comparison with the normal plants, than in the two previous plantings, and for the first time panicles were produced by six of a total of 39 plants in line 3049-9.

Similar dwarf types have been observed in bulk plantings of Straightneck M. N. 29, Straightneck M. N. 51, and Hodo M. N. 48.[2] All plants were dwarfed in two inbred lines (out of 99 grown) of Straightneck M. N. 29. The cause of the abnormality is not known.

Inasmuch as the extremely dwarf plants do not reproduce themselves, it is difficult to study the inheritance of this abnormality. However, in occasional instances, a few viable seeds have been secured from plants exhibiting less pronounced dwarfing. By studying the progenies from such lines it may be possible to determine the inheritance of the dwarfing character.

The importance of this study to the sorgo breeding program, the objective of which is the development of large-stalked, high-yielding, and otherwise improved varieties, is illustrated by data obtained from inbred lines of Straightneck, M. N. 29, and M. N. 51, which possessed the dwarfing character in various amounts but which, nevertheless, were harvested. In five such lines there was an average reduction of 49% in average stalk weight and of 28% in tons of stalks per acre in comparison with the check rows. It is obvious that studies of extent to which dwarfing occurs in breeding stock and determination of the factor, or factors, responsible should facilitate accomplishment of the objective.—A. M. SCHLEHUBER, *Division of Sugar Plant Investigations, Bureau of Plant Industry, Soils, and Agricultural Engineering, Agricultural Research Administration, U. S. Dept. of Agriculture, Meridian, Miss.*

[2]JOHN H. MARTIN, Division of Cereal Crops and Diseases, in a letter received subsequent to the completion of this manuscript, has pointed out that dwarf types have been observed in a number of varieties of sorghum at various times by several workers, including John B. Sieglinger, John H. Martin, and Arthur F. Swanson. The dwarfs have not been observed as constituting the entire progeny from a single plant as was the case with inbred line 3049-9 in this report.

BOOK REVIEWS

EXPERIMENTAL METHODS IN AGRICULTURAL RESEARCH

By H. H. Love. Rio Piedras, P. R.: Agricultural Experiment Station, University of Puerto Rico. V + 229 pages, 1 illus. 1943. $2.00. English and Spanish Editions. (Available at Triangle Book Shop, Ithaca, N. Y.)

THIS book contains five chapters, three statistical tables, and 64 selected references to the literature. Chapter 1, The Measurement of Variability, is a condensed presentation of the usual methods and formulas with a number of worked examples. Chapter II, Analysis of Variance, is devoted largely to discussions of randomized block and Latin square layouts with methods of computation and interpretation of results. Incidentally, in this and succeeding chapters the examples are taken from field plot experiments, using original data and coded values in the computations. Correcting for missing data or plot yields is also discussed. Chapter III, Analysis of Correlation and Covariance, also includes regression and applications of covariance to uniformity trials and control plots. Chapter IV, Practical Application of the Analysis of Variance to Field Experiments, considers the following designs: Combined Latin squares (2 examples,) split-pot experiments, randomized block in a perennial experiment, Latin square manurial experiment with inorganic fertilizer at one level and farmyard manure at three levels, balanced incomplete block, a lattice design, and confounding. Two sections heading are (1) Transformation of Data, explaining the square-root, angular and logarithmetic methods without examples; and (2) The Use of Analysis of Variance in Determining Size and Shape of Plots, using an example in which the computation is abbreviated.

In these four chapters Doctor Love not only discusses the advantages and disadvantages of the designs presented but, except as noted above, gives a very complete and systematically arranged illustration of the computation for each example. Thus, this portion of the volume serves as a computer's handbook for the designs treated. These clear presentations should be especially valuable for the worker who first approaches the subject and, as regards some of the designs, will be of great help to many experimenters who use field plots and have some experience with the analysis of variance. It was impossible to illustrate many designs without greatly increasing the size of the volume. Workers who are interested in other layouts will find carefully selected references to the literature which should guide them to the desired information.

The fifth chapter, General Suggestions for the Conduct of Experiments, may be considered an epitome of an entire volume. In it the author, drawing on the experiences of a life spent on experimental studies, gives one of the finest presentations of the subject known to the reviewer. (Many of the problems are discussed in greater detail in the author's book "Application of Statistical Methods to Agricultural Research," reviewed in this JOURNAL, Vol. 28, pages 867–869.) This chapter could be read with profit by many investigators since it

illustrates how data may be influenced by many factors and shows how all details of an experiment must be taken into account if the data are to be free from serious errors. In the introductory portion of the chapter the importance is emphasized of knowing when to use statistics and when their use may be unwise. Limitation of space prevents more than a mere catalog of the major problems discussed, *viz.*, research projects, the experimental field, uniformity trials, size, shape and replication of plots, design of experiments, the use of sampling for field or other determinations, interpretation of results, and details in conducting experiments, the latter covering many important problems.

The statistical tables are (1) Table for Estimating Probability, (2) Values of F and t, and (3) Values for Interpreting Goodness of Fit. The addition of an index would have been welcome but the Table of Contents serves to assist the reader in finding the main subjects. The clear, concise presentation of so much pertinent information places this work among books the value of which should not be judged by size.—F. Z. HARTZELL.

EMULSION TECHNOLOGY, THEORETICAL AND APPLIED: A SYMPOSIUM

New York: Chemical Publishing Co., Inc. XI + 290 pages, illus. 1943. $5.

TWELVE papers, dealing with the technical aspects of emulsions, constituted a symposium held in London, December 7, 1934, under the auspices of the British Section of the International Society of Leather Trades' Chemists. These papers were published in book form by the British section in 1935 under the title "Technical Aspects of Emulsions", but it is now out of print. The book has since been reprinted, under the pressure of popular demand, and without revision, by the Chemical Publishing Company. Three new sections, by American authors, are added, but the progress made in the last 10 years is not recorded in the original 12 papers.

Regarding the book itself, it is a unique assembly of industrial and technical phases of emulsions, and will be of interest to all concerned in any way with the production or utilization of emulsions. The volume is opened by H. Freundlich, with a short but interesting account of his investigations with ultra sonics and the mechanism of emulsification. Miss R. M. Cobb discusses the fundamental principles of practical emulsion manufacture in section 2. A typographical error occurs on page 10 in the expression of Stokes' law; the numerical coefficient is 2/9 and not 1/18.

The third section comprises a report by V. C. Walsh and A. C. Frazer relative to their investigations involving the use of highly dispersed emulsions in the alleviation of toxic conditions in human beings suffering from bacterial diseases. The fourth section is a voluminous survey of the patent literature by William Clayton. Two hundred and forty four patents are cited. The book is worthy of attention for this section alone.

The problems of general formulation in connection with lyophylic and lyophobic colloids acting as emulsifying agents and with methods of emulsification are dealt with by M. P. Hofman in the fifth section. Questions pertaining to the development of emulsifying machines, whisks, colloid mills and homogenisers, their design and range of usefulness are considered by Robert Johnson in section six.

In section 7, R. Corey discusses the effect of the mode of preparation on the dispersion of soap-stabilized vegetable oil emulsions in the light of experiments dealing with emulsification by soap formation *in situ*.

Section 8 has to do with the preparation and application of emulsions used in agriculture, chief consideration being given to the uses of emulsions as summer and dormant sprays, as herbicides, as fungicides, to the retention of the oil by the foliage, the removal of the oily residue, and to their uses as insecticides in the control of insect pests of man and animal. The section is developed by R. M. Woodman.

Mayonnaise is dealt with by J. W. Corran in section 9 as an example of a typical food emulsion, and consideration is given to the uses of egg yolk and mustard as emulsifying agents, and to conditions of manufacture in relation to the question of stability.

In Section 10, Speakman and Chamberlain develop the subject of emulsification and emulsions in the wool textile industry, and discuss the properties of thin films of oil in relation to the scouring process. The stability of emulsions in thin films and the role they play in emulsion paints of the oil-in-water type are considered in section 11 by L. A. Jordan, and this section immediately precedes the section by Wortham on interior oleoresinous emulsion paints. In section 13 W. R. Atkin and F. C. Thompson consider the uses of emulsions in the leather industry. The last two sections have to do with rubber latex in relation to the harvesting of rubber (by H. P. Stevens and W. H. Stevens), and to some of the physical properties (by L. G. Gabriel) of dispersions of asphaltic bitumin, particularly in connection with road construction—VERNON L. FRAMPTON.

PLANT VIRUSES AND VIRUS DISEASES

F. C. Bawden. Waltham, Mass.: Chronica Botanica Company. Ed. 2. XI + 294 pages, illus. 1943. $4.75.

THE first edition of this book was published in Leiden, Holland, in 1939. The second edition is somewhat larger, both in size of format and number of pages. The author is head of the Plant Pathology Department, Rothamsted Experiment Station, Harpenden, Herts., England. In the preface, the author states that half of the chapters have been rewritten and all have been modified to some extent. The more extensive alterations have been made in chapters dealing with properties of viruses *in vitro* and with their relationship to insect vectors. The chapter titles remain essentially the same, except that a chapter on "Inactivation of Viruses" has been introduced.

The book is an excellent summarization of the present knowledge, and especially the more recent researches, on plant viruses. Along with this, the author has drawn extensively on his own investigation and experience with viruses and presents conclusions and judgments which are both interesting and sound. Many controversial subjects are discussed, but the author has generally taken the point of view that further researches are necessary to permit final conclusions, and little opportunity for disagreement on principles is to be found.

The book deals largely with the plant viruses as causative agents of disease. Little or no direct information about specific virus diseases of plants as such is given, and perhaps to this extent the title is too inclusive. It is significant that the author of this book deals largely with the viruses as entities which justify treatment independently quite as much as do the bacteria and the fungi, even though the viruses are usually more dependent upon the host plants for their existence. Accordingly, the author points out, for example, the value of studies on the properties *in vitro*, the serological reactions, and the chemical nature of the viruses as a basis for separation.

Much of the book is naturally concerned with the chemical nature of the viruses, which has been the author's special sphere of interest. To those less actively engaged in this phase, the subject may appear to be somewhat overemphasized in relation to other divisions of virology. Although the protein nature of the viruses is now generally accepted, too little is known about protein chemistry as a whole, or virus protein in particular, to distinguish living forms. The true nature of viruses, or their origin, therefore remains quite as much a mystery as before the molecular size and behavior of the virus molecules were computed. Bawden's book will prove stimulating to those who wish to enter or continue this entrancing field of research. It is perhaps too advanced for elementary college students of plant pathology, but should be made available to all pathological laboratories in both the plant and the animal field.

One of the reasons given in the preface for rewriting the second edition was the destruction of the original type during the invasion of the Netherlands. Considering the conditions of aerial warfare, it is heartening to research workers everywhere to know that essentially pure scientific work may be continued, and is continued, practically at the battle front.—James Johnson.

SOIL GROUPS AND SUB-GROUPS OF SOUTH AFRICA

By C. R. Van der Merwe. Pretoria: Dept. of Agriculture and Forestry, Union of South Africa. Science Bulletin 231; Chemistry Series 165. 361 pages, illus., Maps. 1940–41.

THE results of systematic laboratory and field studies of soil types, begun about 1929, are summarized in this progress report. The detailed discussion of about 70 soil profiles is supported by data from the mechanical and chemical analyses of some 350 soil horizons. Sixteen soil profiles are illustrated in color. The genetic and geographic relationships of the soils to climate, parent material, and vegetation are dealt with and illustrated by small-scale lithographed maps of

vegetation, geological formations, and soil groups. Considerable is also said regarding the use of the soils.

The author presents two tentative classifications, differing in detail. The following accompanies the map:

(A) Summer-rainfall area:

a) *Desert soils:* (1) Soils with lime horizon. (2) Brak soils. (3) Very shallow soils. (4) Rock (Hills and plains).
b) *Solonetzic soils:* (1) Alkali soils.
c) *Kalahari soils:* (1) Kalahari sand. (2) Kalahari sand on lime.
d) *Unleached subtropical soils:* (1) Black clay soils. (2) Reddish-brown sandy soils (Low Veld).
e) *Lithological types:* (1) Waterberg and Zoutpansberg light brown sandy soils and Waterberg sandstone. (2) Lydenburg dark brown sandy soils and Pretoria quartzite. (3) Drakensberg black clay soils and basalt.
f) *Gley-like podzolic soils:* (1) High Veld prairie soils. (2) Eastern province semi-coastal belt soils. (3) Natal coastal belt soils (Sugar belt).
g) *Laterite and lateritic soils:* (1) Laterite and lateritic red earths. (2) Lateritic yellow earths.
h) *Ferruginous lateritic soils:* (1) Grey ferruginous lateritic soils. (2) Brown to reddish-brown ferruginous lateritic soils.
i) *Miscellaneous types:* (1) Eastern littoral light brown sandy soils. (2) Aeolian sandy soils (North-Western O.F.S.)

(B) Winter-rainfall area:

(1) Grey sandy soils and table mountain sandstone. (2) Gravelly sandy clay loam on clay. (3) Sandy loam on lime and clays. (4) Reddish-brown sandy loam on lime and and sandy loams (Deep). (5) Coastal Aeolian sand on lime and sandy soils. (6) Shifting sand.

Although the book contains a wealth of chemical data of great interest to soil scientists, it is obvious from the foregoing that these and the field data have not been systematically arranged. As in many regions, extremes of parent material are reflected in the soil, thus tending to obscure the more general regimes of soil development. The classification is an incoherent pattern of inconsistently defined and named categories based, unevenly, upon climate, parent material, texture, color, genetic soil characteristics, and regional geographic features. These inconsistencies reduce the value of the map.

Too much should not be made of the weakness in classification, because of the importance of the basic data presented for South Africa. With more study, especially in the field, the boundaries between types can be located more precisely and the groups more carefully defined in relation to one another and to the soil groups of the world. The book is a valuable contribution to soil geography.—CHARLES E. KELLOGG.

HANDBOOK OF CHEMISTRY

Compiled and edited by N. A. Lange, assisted by G. M. Forker and R. S. Burington. Sandusky, Ohio: Handbook Publishers, Inc. Ed. 5. XVI+2076 pages, flexible cover. 1944. $6.

DURING the past two decades those dealing with the natural sciences have come to regard handbooks as essential tools. While we now take them for granted, this may be a good occasion to realize the important services which they render in our daily work.

They give information for which one would have to search the library—and few libraries could possibly have more than a part of the original data. They also give us information compiled in a systematic manner which actually could not be had elsewhere.

The fifth edition of the *Handbook of Chemistry* is outstanding on both counts. It is a far cry from the early editions of English handbooks and the Chemiker Kalender. The topical variety of the information included is enormous. There is no need here to discuss the contents except that several new chapters on the periodic table, flammable liquids, plastics, fluorescence, and industrial water have been added and many others rewritten and extended. The list of 6,507 organic compounds giving their physical properties and 3,600 additional synonyms as footnotes alone would make this volume indispensable. The index contains 3,600 entries.

It is difficult to see how anyone dealing with the natural sciences could justly avoid the constant use of this splendid handbook without spending precious hours in search of textbooks and libraries for data. The reviewer feels that this volume is a real contribution to the scientific literature and an important factor in making research work more efficient.—Z. I. KERTESZ.

FOOD AND FARMING IN POST-WAR EUROPE

By P. Lamartine Yates and D. Warriner. London, New York, Toronto: Oxford University Press. V+118 pages, illus. 1943. 3s. 6d. net.

THIS is an admirably clear and informative little book on the peasantry of Europe. These 170 million people, depressed and exploited ever since the Industrial Revolution, are surely in need of fulfillment of the obligation which the United Nations incurred in promising "Freedom from Want".

The rehabilitation and rebuilding of Europe after the war will depend to a great extent on the success of efforts to improve the lot of the farming peasantry. This will be especially true in eastern Europe, where they make up 60 to 70% of the population. They must be able to produce food again and must become more efficient than they were in the past due to many factors mostly beyond their power to remedy.

The complicated subject is presented through sketches of the daily life of farmers in various countries. After discussing the possible approaches to improve the lot and efficiency of the peasantry, another set of sketches show how much difference the proposed reforms would make in the life and efficiency of the same farmers which have been pictured under the present system. The little volume is written in the most enjoyable style and makes one hope that more informative books of this nature will be written and widely read.—Z. I. KERTESZ.

AGRONOMIC AFFAIRS

APPRECIATION OF THOMAS JEFFERSON ON THE OCCASION OF THE TWO HUNDREDTH ANNIVERSARY OF HIS BIRTH

THOMAS Jefferson's efforts in behalf of agriculture are being given special recognition this year. No group of American citizens has more reason to honor his memory than agronomists. All citizens find both inspiration and solid fundamentals in his writings, and in the moral character of the man. Agronomists find these things, and much besides. The Jefferson who was statesman and philosopher is better known, perhaps, than the Jefferson who was also the careful farmer of stubborn Davidson soil, the keen observer of agricultural science and practice in many lands, the founder of agricultural curricula and libraries, and the agricultural scientist and geographer.

In recognition of the great contributions that he made to agricultural science and to the welfare of American agriculture, the Congress of the United States has passed a joint resolution providing for the creation of a National Agricultural Jefferson Bicentenary Committee.[1] This Committee is undertaking to sponsor and promote appropriate activities in honor of Thomas Jefferson. Because of certain unavoidable delays, the Committee was not organized until a considerable time after the two hundredth anniversary of his birth—April 13, 1943. A pilgrimage to Monticello is planned for April 13, 1944, insofar as possible under wartime conditions, by representatives of the Land Grant colleges and other persons interested in both agriculture and Thomas Jefferson.

Of greatest importance will be the programs and activities carried on by the many cooperative groups of citizens, such as the American Society of Agronomy, that result in calling the attention of agricultural people generally to the great contributions of Jefferson. He was concerned not only with practical farming but also with fundamental scientific principles. He realized that science and practice went together: For him there was no valid choice between practical success and deep scholarship; each was essential to the other. Jefferson was also a profound geographer who saw the basic importance of both local and regional geography to agriculture as well as to political development. His *Notes on the State of Virginia*, his basic thinking that helped President Monroe formulate the famous message to the Congress on the relation of other nations to the New World, his grasp of the importance of the Louisiana Territory, and his support of the Lewis and Clark expedition testify abundantly to this aspect of his scholarship.

Young men, and older ones as well, of all phases of agronomy and soil science will find inspiration and stimulus from the work and life of Jefferson. The universality and symmetry of his scholarship in art, science, justice, and morality are rarely seen combined in one person.

Members of the Society are urged to give special emphasis this year to their own reading of Jefferson. Beyond this it is hoped they

[1]Public, No. 196, 78th Cong., Chap. 333, 1st Sess., S. J. Res. 47.

will call the attention of the public to his contributions to agricultural science and practice. This may be done through specially prepared papers, in lectures, and in more popular articles. The agricultural press is anxious to have short articles about Jefferson of, say, 250 to 1,000 words, especially those of an anecdotal nature.

Jefferson maintained a very large correspondence and only a relatively small part of this has been published. In addition there is a great deal of writing about him, widely scattered. Perhaps one of the best sources of material is the Library Edition of *The Writings of Thomas Jefferson*, edited by Andrew G. Lipscomb and published at Washington in 1903 under the auspices of the Thomas Jefferson Memorial Association. Recently, Everett E. Edwards[2] has compiled a most useful and interesting group of excerpts from Jefferson's writings dealing with agriculture, and Charles A. Browne[3] has prepared an excellent summary statement of Jefferson's appreciation of and participation in scientific research, including agricultural science, illustrated with many quotations and contemporary maps and drawings.

As a representative of the American Society of Agronomy on the National Committee, I should like to urge that members dip into Jefferson's storehouse of experience and scholarship and make special efforts to give publicity to his important contributions to agricultural science and thought. At the same time, I should welcome ideas and suggestions from members regarding ways to stimulate appreciation of Jefferson's work, or to honor him, that should be brought to the attention of the National Committee or to the Executive Committee of our Society.—CHARLES E. KELLOGG, *Chief, Division of Soil Survey, Bureau of Plant Industry, Soils and Agricultural Engineering, U. S. Dept. of Agriculture.*

---

[2]EDWARDS, EVERETT E. Jefferson and agriculture. 92 pp. (Mimeographed). Agricultural History Series. No. 7. U. S. Dept. of Agr. 1943.

[3]BROWNE, CHARLES A. Thomas Jefferson and the scientific trends of his time. 63 pp. illus. Chronica Botanica. vol. 8. Reprint No. 1. Waltham, Mass. 1943.

NEWS ITEMS

DOCTOR C. G. ATWATER, formerly with the Barrett Company and an active member of the American Society of Agronomy since 1914, has retired from active work and is now making his home on a farm at Chadds Ford, Pa.

—A—

THE SOCIETY OF AMERICAN FORESTERS announces the publication of a glossary of technical terms used in forestry entitled, *Forestry Terminology*. Some 4,500 words and terms are defined, including the fields of forest management and economics, silviculture, forest mensuration, wood technology, lumbering and wood-using industries, wildlife and recreation, range management, forest fire control, forest entomology, and forest pathology. The book is priced at $2.00 postpaid and may be obtained from the Society of American Foresters, 825 Mills Building, 17th Street and Pennsylvania Avenue, N. W., Washington 6, D. C.

JOURNAL

OF THE

American Society of Agronomy

VOL. 36 | MAY, 1944 | NO. 5

UTILIZATION OF PLANT RESIDUES FOR THE PRODUCTION OF ARTIFICIAL MANURES[1]

JAMES P. MARTIN AND YUEH WANG[2]

FARMYARD manure, green manure, and plant residues are commonly used as sources of organic matter for the soil. As a consequence, of the limited supply of farmyard manure in certain areas, it may prove of value to produce artificial manure from various plant residues which are available on the farm. Hutchinson and Richards (7)[3] were among the first to produce artificial manure on a practical basis. The following conditions were outlined as essential for the production of artificial manure from straw: Proper aeration and temperature, an adequate supply of soluble nitrogen, and a neutral or slightly alkaline reaction. It was concluded that the addition of 0.7 to 0.75 parts of nitrogen to every 100 parts of dry straw gave the best results.

Albrecht (1) suggested the use of a mixture of 45% ammonium sulfate, 15% superphosphate, and 40% limestone to be applied at the rate of 150 pounds per ton of wheat straw. This resulted in the formation of a very good manure within 3 to 5 months. When applied to soil seeded to wheat and later to clover, it was more beneficial than was straw or barnyard manure. Smith and Brown (13) reported that a good quality artificial manure could be produced by composting straw or cornstalks with chemicals and adding sufficient water. Waksman and Reneger (18) studied the production of artificial manure for the growth of mushrooms and found that a mixture of straw and alfalfa without the addition of inorganic salts gave good results. Other investigations (3, 4, 5, 6, 8, 10, 12, 15) have tended to confirm the results of Richards and Hutchinson.

The present report is concerned with the production of artificial manure from several organic residues that might be available in New Jersey, namely, oat straw, clover hay, peat, leaves, cornstalks,

---

[1]Journal Series Paper, New Jersey Agricultural Experiment Station, Rutgers University, Department of Soil Chemistry and Microbiology, New Brunswick, N. J. Received for publication August 24, 1943.

[2]Formerly Assistant Soil Microbiologist, New Jersey Agricultural Experiment Station, now Assistant Bacteriologist, University of Idaho, Moscow, Idaho; and Graduate Assistant, respectively. The authors wish to thank S. A. Waksman under whose suggestion and guidance this study was undertaken.

[3]Figures in parenthesis refer to "Literature Cited", p. 384.

salt-grass hay, and woody materials. The transformation of the residues during decomposition and the quality of the artificial manures produced were studied.

MATERIALS AND METHODS

Eight composts, each containing 1,000 pounds of the respective dry organic material, were made as follows:

1. Oat straw + inorganic salts (34 pounds $(NH_4)_2SO_4$, 10 pounds superphosphate, and 30 pounds $CaCO_3$)
2. Oat straw (700 pounds) + clover hay (300 pounds)
3. Lowmoor sedge and reed peat (700 pounds +) timothy hay (300 pounds)
4. Cow manure with oat straw bedding
5. Cornstalks + inorganic salts (34 pounds $(NH_4)_2SO_4$, 10 pounds superphosphate, and 30 pounds $CaCO_3$)
6. Salt-grass hay + inorganic salts (34 pounds $(NH_4)_2SO_4$, 10 pounds superphosphate, and 30 pounds $CaCO_3$)
7. Leaves (500 pounds) + woody residues of oak, ash, and maple (500 pounds) + inorganic salts (17 pounds $(NH_4)_2SO_4$, 5 pounds superphosphate, and 15 pounds $CaCO_3$)
8. Leaves (700 pounds) + timothy hay (300 pounds)

The individual composts were set up close together so that they constituted a row of piles. They were separated by chicken wire and rested on a wooden structure so arranged that most of the liquid escaping from any particular pile could be collected and returned to that pile. The heaps were built in layers, inorganic salts (if required) and water being added after each layer had been laid. The salt-grass hay, leaves, and straw did not compact readily; they were, therefore, tramped down after each layer was completed. During the course of decomposition, additional water was added as needed to the tops of the piles in order to maintain the moisture content at approximately 75%.

After 30, 70, and 110 days, the piles were turned, sampled, and repiled. The fresh samples were analyzed for total ammonia, nitrate nitrogen, and pH. The remainder of the samples was dried, ground, and used for chemical analysis in accordance with the system of Waksman and Stevens (19). Ammonia and nitrate nitrogen were determined by the Shirkhande method (11), and total nitrogen was determined by the official Kjeldahl method (2).

The temperature of each compost was taken at frequent intervals by running a thermometer to the center of the piles through copper tubes arranged for the purpose.

The composting period was considered complete when the nitrogen content approximated 2.3 to 3%. Composts 1 to 5, inclusive, were completed by December. They were soaked with water and tramped down tightly in order to create anaerobic conditions and thereby reduce further decomposition to a minimum, and also to prevent nitrate formation and consequent loss of nitrogen by leaching or by biological action. They were left in this condition until March and May when they were used for plant growth tests.

The completed or mature composts were weighed to determine the total amount of artificial manure produced and the percentage decomposition of the original organic material.

RESULTS

TRANSFORMATION OF ORGANIC RESIDUES DURING COMPOSTING

Shortly after the composts were set up, the temperatures inside the piles increased rapidly. In the composts of oat straw + inorganic salts, oat straw + clover hay, cornstalks, and leaves + timothy hay, it rose to approximately 70° C, which showed that very active decomposition was occuring. Although the temperatures in the the other composts were not so high, they rose sufficiently to indicate that considerable decomposition was taking place there as well. After the

first turning of the composts, the temperatures again rose rapidly, reaching magnitudes almost as high as when the piles were first made. At this time, however, heat evolution decreased more rapidly than at first. This was especially true with the compost of cornstalks. After the second turning, the temperature again increased, but the maximum values were not nearly so high as in the previous cases and they rapidly subsided to atmospheric temperature values.

The salt-grass hay decomposed very slightly, which was probably due to its physical nature. It did not absorb water, and the chemicals added were lost by leaching. This material was allowed to compost fully over the winter months; half of the original amounts of the inorganic salts were then again added, and the composting was continued. After 380 days, samples were taken for proximate chemical analysis. The results indicated extensive decomposition of the salt-grass hay and suggested that salt-grass hay can also be composted if sufficient time is allowed. The woody material in the compost of leaves + woody residues decomposed very slowly, whereas the leaves decomposed rapidly, thus making accurate sampling difficult. For these reasons, no detailed report is made for the salt-grass hay and leaves and woody residues composts.

The compositions of the other composts before and after composting are given in Table 1. The original compositions were calculated from the analyses of the individual components.

The cornstalks decomposed much more rapidly than the other organic residues; after 70 days, decomposition was considered complete. The other organic materials were not sufficiently decomposed until after 110 days. The materials that reached the end stage after 4 months or less of composting appeared similar to stable manure, with the exception of the peat + timothy hay.

The fatty and waxy substances decomposed largely in all composts (73.0 to 91.5%). The water-soluble organic matter is derived from at least three different sources, namely, (a) from that present in the original organic material, (b) from the decomposition products of the breakdown of the more complex organic constituents, such as hemicelluloses and cellulose, and (c) from the synthesis of simple organic compounds by the microorganisms. A determination, therefore, of the exact loss of the original water-soluble organic matter during composting is impossible. The extensive reduction of this fraction (46.5 to 80.9%) however, shows the rapidity with which it is attacked by microorganisms.

The changes in hemicelluloses and cellulose were no less extensive than those recorded in previous work (16, 17, 20) on composts containing straw, and amounted to 60 to 80% of the hemicelluloses and 80 to 90% of the cellulose.

The results show definitely that the lignins were also decomposed. The extent of their decomposition, however, depended greatly upon the type of plant material. There was extensive decomposition of lignins in the composts of oat straw + clover hay, cow manure, peat + timothy hay, and leaves + timothy hay (38.4 to 55.5%). The lignins in the compost of oat straw + inorganic salts also decomposed, but to a very small extent (13.9%). The cornstalks, however, showed

TABLE 1.—*Decomposition of organic constituents during composting in grams per 100 grams of original material.*

Constituents analyzed	Oat straw + inorganic salts			Oat straw + clover hay			Cow manure			Peet + timothy hay			Cornstalks + inorganic salts			Leaves + timothy hay		
	At start	At end (110 days)*	Loss or gain, %	At start	At end (110 days)*	Loss or gain, %	At start	At end (110 days)*	Loss or gain, %	At start	At end (110 days)*	Loss or gain, %	At start	At end (70 days)*	Loss or gain, %	At start	At end (250 days)*	Loss or gain, %
Total material	100	44	56	100	34	66	100	47	53	100	62	38	100	49	51	100	38	62
Ether-soluble portion	2.4	0.34	−86	2.4	0.23	−91	1.6	0.23	−86	1.3	0.17	−86	1.4	0.13	−91	2.8	0.76	−73
Water-soluble organic matter	9	2.34	−74	10.5	4.60	−56	9	3.41	−62	5.0	2.66	−46	15.5	2.66	−83	11.7	2.25	−81
Hemicelluloses	16.5	5.55	−66	15.5	4.17	−73	15.7	2.82	−82	10.5	4.17	−60	20.0	3.69	−81	13.0	3.48	−73
Cellulose	33.0	4.19	−87	30.8	5.10	−83	18.9	1.60	−92	7.8	-0.88	−90	27.4	3.94	−86	15.7	1.82	−88
Lignin	13.4	11.55	−14	13.6	8.00	−41	20.8	11.00	−47	38.0	22.40	−38	9.5	10.12	7	25.1	11.30	−55
Crude protein	1.7	5.11	+197	3.8	4.05	+7	9.1	8.25	−10	14.5	12.15	−16	2.0	4.90	+147	5.5	3.76	−32
Ash	5.5	9.65	+75	5.77	5.77	+4	17.3	17.38	0	10.7	12.91	+21	6.3	14.05	+124	10.2	10.50	+3
Total N	1.36†	1.03	−24	1.24	0.85	−26	2.16	1.44	−33	2.38	2.00	−13	1.28*	1.09	−15	1.13	0.70	−38
Total N‡	—	2.34	—	—	2.50	—	—	3.07	—	—	3.22	—	—	2.23	—	—	1.84	—

*On basis of 100 grams of original material.
†Includes 0.7% N added with inorganic salts.
‡Percentage in end-product.

no indication of lignin decomposition. There is no doubt, however, that were the composting period long enough, the lignins of cornstalks would be attacked also.

With an outside source of inorganic nitrogen, as in the oat straw and cornstalks composts, large amounts of crude protein (197.0 and 147.5% of the amounts originally present, respectively) were synthesized by the microbes. Where there was no outside supply of inorganic nitrogen, the organic nitrogenous compounds present in the plant residues were attacked and transformed into the cell materials, which in turn were attacked and resynthesized. In the compost of oat straw + clover hay, the decomposition and synthesis occurred at approximately the same rate, and therefore the amount of protein in the compost changed very little. In the composts of cow manure, peat + timothy hay, and leaves + timothy hay a greater rate of decomposition over synthesis occurred, as shown by the decrease in the protein contents.

Loss of nitrogen (13.5 to 38.0%) was observed in all composts. Since the reaction of the compost was nearly neutral, possibility of volatilization seems unlikely. Despite the fact that special care was taken to collect all the leachings and return them to the compost heap, the loss of nitrogen was probably due to the leaching action of the rain. No nitrate nitrogen was found in these composts.

A determination of the total artificial manure produced from the materials and the percentage decomposition of the compost materials showed that, in general, 1,000 pounds of the original dry organic residues produced 1 ton of moist artificial manure. Approximately 50 to 60% (Table 1) of the organic material was lost by decomposition. The least decomposition occurred in the compost of peat + timothy hay (38.0%), and the most in the compost of oat straw + clover hay (66.0%).

AVAILABILITY OF PLANT NUTRIENTS IN THE ARTIFICIAL MANURES

The plant nutrients which are considered to be the most essential with respect to quantity are nitrogen, phosphorus, and potassium. The availability of these three elements in composts varies greatly. In order to evaluate these nutrients, greenhouse and field tests are most commonly made. Ammonification and nitrification procedures for the study of the availability of the nitrogen have also been utilized. More recently, use has been made of the principle of the nutrient requirements of certain microorganisms as an indicator of availability of potassium and phosphorus in the soil. In this study, these methods were used to evaluate five of the composts.

The nitrification and *Aspergillus niger* tests agreed very well with the greenhouse tests and therefore need not be discussed here.

GREENHOUSE TESTS

In the greenhouse studies, the tests were carried out in pots. Penn loam soil, limed to a pH of 6, was used. The treatments were as follows: 1, Control; 2, fertilizer; 3, oat straw + inorganic salts compost; 4, oat straw + clover hay compost; 5, lowmoor peat + timothy hay compost; 6, cornstalks + inorganic salts compost; and 7, cow manure compost.

The fresh composts were mixed with soil at the rate of 50 tons per acre. For treatment 2, fertilizer was added at the rate of 2,000 pounds of 5–10–10 per acre. All the composts were reinforced with a small amount of superphosphate, the exact amount depending on the phosphorus content of the material. The peat + timothy hay compost received a small amount of potassium chloride in addition to phosphorus.

Tomatoes, followed by barley, were planted in replications of six in one series of pots and carrots in replications of four in another. All the pots in which carrots were planted contained 15 pounds of soil. Half the tomato pots contained 15 pounds and the other half 7.5 pounds of soil.

Tomato and barley series.—After the tomato plants had recovered from transplanting, their appearance under the various treatments was similar, except that the plants growing in the soil treated with composted cow manure looked a little more vigorous than the others. The control plants grew very poorly. The composts of oat straw + inorganic salts and of oat straw + clover hay produced only poor growth of the plants at first, but later slight improvement was noted. The plants growing in the soils treated with cornstalks and cow manure composts developed much better than the others (Fig. 1). All the plants were vigorous and healthy. The inorganic fertilizer and peat compost treatments appeared to be intermediate in their effect.

After 2 months, the tomato plants were harvested and the average fresh and dry weights for each treatment determined (Table 2). All treatments produced an increase in growth over the controls. The cornstalks and cow manure composts were markedly more beneficial than the complete fertilizer. It is evident that neither the compost of oat straw + inorganic salts nor oat straw + clover hay produced as high a quality manure as the cornstalks and the cow manure composts; or, possibly the former composts were not allowed to decompose sufficiently for best results. Peat must be reinforced with fertilizer for best results. The cornstalks compost was slightly more beneficial than the cow manure compost.

Barley was planted after the tomatoes were harvested to determine the residual effects of the composts. The barley was allowed to grow for 2 months, at which time it was harvested and the average fresh and dry weights determined. As would be expected, the residual effects of the organic materials were much greater than that of complete fertilizer treatment (Table 2 and Fig. 2). The first crop removed most of the available plant nutrients applied with the inorganic fertilizer. The composts of cow manure, oat straw + clover hay, cornstalks, and oat straw + inorganic salts, in the order named, brought about the greatest increase in growth of barley.

The meager effect of the composts of oat straw + clover hay and oat straw + inorganic salts on the growth of the tomatoes and their very beneficial effect upon the growth of barley make it apparent that these materials had not decomposed sufficiently when they were first added to the soil, but that they were capable of producing a good quality artificial manure. For the best results, the straw composts would have to be composted longer or would have to be applied to the

soil several weeks before planting. The barnyard manure had a slightly greater residual effect upon plant growth than the artificial manures.

FIG. 1.—Effect of artificial manure on the growth of tomato plants. Left to right: Control, cornstalks compost, and composted cow manure.

Carrot series.—The carrots were grown for 3 months. At first, the plants growing in the soils treated with the cornstalks and cow manure composts were much larger than the others. The control, the fertilizer, the composts of oat straw + clover hay, oat straw + inorganic salts, and peat + timothy hay supported the poorest growth. During the later stages of growth, the plants in the soils treated with

TABLE 2.—*Greenhouse tests of the effect of various composts upon the growth of tomatoes and barley, with composts added at rate of 50 tons per acre.*

Treatments	Tomatoes			Barley*		
	Average per pot		Increase over control, %†	Average per pot		Increase over control, %†
	Fresh weight, grams	Dry weight, grams		Fresh weight, grams	Dry weight, grams	
Control	7	1.0	—	10	2.0	—
Fertilizer (2,000 lbs. per acre of 5–10–10)	73	13.1	1,210	14	3.7	85
Oat straw + inorganic salts	48	8.0	700	27	6.2	210
Oat straw + clover hay	41	6.5	550	40	9.5	375
Peat + timothy hay	36	6.3	530	17	3.9	95
Cornstalks + inorganic salts	147	22.8	2,180	36	7.7	285
Cow manure	114	18.7	1,770	48	11.3	465

*Barley following tomatoes in same culture medium.
†Calculated on dry weight basis.

fertilizer and the compost of oat straw + clover hay began to grow more vigorously and soon became larger than the plants of all the other treatments, except those produced with the cornstalks and cow manure.

Yield data for the carrot experiment are recorded in Table 3. They are the average of four replications, each containing eight carrot plants. The results are very similar to those obtained with the tomatoes, except that the compost of oat straw + clover hay was more beneficial than the compost of oat straw + inorganic salts.

TABLE 3.—*Greenhouse tests of the effect of artificial manures and other treatments upon the growth of carrots, with composts added at the rate of 50 tons per acre.*

Treatments	Average fresh weight of tops and roots, grams	Average fresh weight of roots, grams	Increase of fresh roots, %
Control	12	4	—
Fertilizer (2,000 lbs. per acre of 5–10–10)	121	77	1,800
Oat straw + inorganic straw	31	19	370
Oat straw + clover hay	60	31	670
Peat + timothy hay	42	29	620
Cornstalks + inorganic salts	192	146	3,500
Cow manure	156	122	2,900

FIELD TESTS

Based on the results of the greenhouse tests, a field study was made which was designed to determine the effect of the same five composts

upon plant growth. Small wooden frame plots (3 × 4 feet) were used. Radishes (White Icicle) followed by carrots (California) were grown in one series of plots and sweet corn (Golden Bantam) in a second series. The soil in the radish series was Sassafras silt loam and in the corn series Sassafras sandy loam. Treatments were duplicated for each crop and were as follows: 1, Control; 2, fertilizer (1,000 pounds 5–10–10 per acre); 3, oat straw + inorganic salts compost; 4, oat straw + inorganic salts compost, + fertilizer (250 pounds 5–10–10

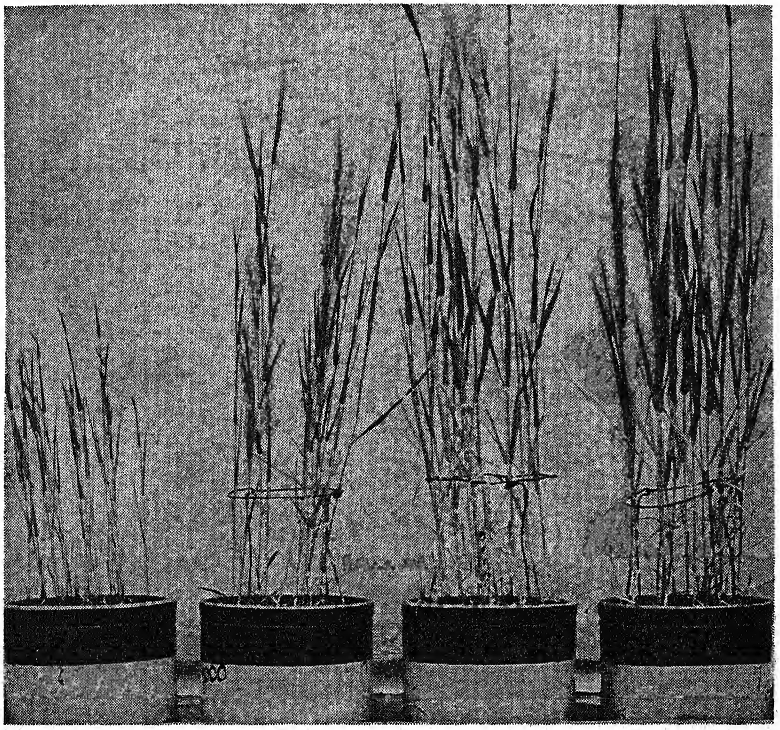


FIG. 2.—Residual effect of the artificial manures on the growth of barley. Left to right: Control, cornstalks compost, oat straw + clover hay compost, and composted cow manure.

per acre); 5, oat straw + clover hay compost; 6, oat straw + clover hay compost, + fertilizer (250 pounds 5–10–10 per acre); 7, lowmoor peat + timothy hay compost, + fertilizer (500 pounds 5–10–10 per acre); 8, cornstalks + inorganic salts compost; and 9, cow manure compost.

All the compost materials were applied at the rate of 20 tons per acre and were reinforced with superphosphate at the rate of 250 pounds per acre.

After the plants were harvested, fresh and dry weights of corn tops and radish and carrot tops and roots were obtained. Nitrogen determinations were made on all the plant materials harvested.

Radish and carrot series.—The radishes were harvested 35 days after planting. The average yields per plot and the nitrogen content of the plants are recorded in Table 4. As was the case in the greenhouse experiments, the cornstalks and cow manure composts exerted a much greater influence than the others. The complete fertilizer increased top growth much more than root growth. The addition of a small amount of fertilizer to the two straw composts increased their effectiveness; however, they were still not so beneficial as the complete fertilizer with respect to total plant material produced. From the point of view of root growth, on the other hand, the difference in the beneficial effects of the complete fertilizer and the two straw composts reinforced with fertilizer was not very marked.

TABLE 4.—*Field tests of the effect of composts upon the growth of radishes.*

Treatments	Dry weight of tops, grams*	Dry weight of roots, grams	Dry weight of tops and roots, grams	Nitrogen in crop, %	Nitrogen removed by crop, grams	Increase in whole plant, %†	Increase in roots, %
Control	47.6	18.9	66.5	4.00	2.66	0	0
Fertilizer	95.8	34.9	130.7	4.46	5.83	96	85
Oat straw + inorganic salts	52.7	30.2	82.9	3.49	2.90	25	60
Oat straw + inorganic salts + fertilizer	58.6	34.3	92.9	3.62	3.37	40	81
Oat straw + clover hay	52.3	23.6	75.9	3.83	2.91	14	25
Oat straw + clover hay + fertilizer	55.2	29.8	85.0	3.96	3.37	28	58
Peat + timothy hay + low fertilizer	65.6	31.5	97.1	4.13	4.01	46	67
Peat + timothy hay + high fertilizer	63.4	38.0	101.4	4.26	4.32	52	101
Cornstalks + inorganic salts	81.7	50.4	132.1	3.89	5.14	99	167
Cow manure	85.7	45.9	131.6	3.15	4.15	98	143

*All figures represent plot averages.
†Increase in plant growth due to treatment.

The plants growing in the control and in the plots treated with composts of oat straw + inorganic salts and oat straw + clover hay removed the least amount of nitrogen from the soil. It is probable that nitrogen was a limiting factor for growth; however, the percentage nitrogen of the plants from these treatments was considerably more than in the case of the cow manure compost treatment. It is possible that in the latter case, a more favorable balance of nutrient was present and made possible a more economical utilization of the available nitrogen by the plants. The greatest amount of nitrogen was removed from the plots treated with complete fertilizer. The fact that other treatments produced greater yields than the fertilizer indicates that factors other than that of available nitrogen were responsible for the better growth. It is possible that the organic manures supplied

certain minor elements and improved the physical properties of the soil, both of which contributed to the increased plant growth.

As soon as the radishes were harvested, the soil in the plots was spaded, raked, and planted to carrots. The carrots were harvested after 3 months and were subjected to the same analyses as were the radishes (Table 5). The residual effect of the complete fertilizer was slight, but that of all the artificial manures treatment was considerable. The oat straw + clover hay compost followed by the peat + timothy hay compost (high fertilizer) had the greatest residual effect. They were followed by the composts of oat straw + inorganic salts, cornstalks, and manure which were approximately equal in this respect. The percentage nitrogen of the carrots from the various plots was similar.

TABLE 5.—*Field tests of the residual effect of composts upon the growth of carrots.*

Treatments	Dry weight of roots, grams	Dry weight of tops and roots, grams	Nitrogen in crop, %	Nitrogen removed by crop, grams	Increase, whole plant, %*	Increase, roots, %*
Control	260	456	1.03	4.69	0	0
Fertilizer	276	487	1.10	5.38	7	6
Oat straw + inorganic salts	335	557	1.17	6.50	22	29
Oat straw + inorganic salts + fertilizer	332	524	1.02	5.33	15	24
Oat straw + clover hay	401	665	1.11	7.39	46	64
Oat straw + clover hay + fertilizer	373	608	1.09	6.62	33	43
Peat + timothy hay + low fertilizer	297	516	1.19	6.16	13	14
Peat + timothy hay + high fertilizer	377	616	1.04	6.43	35	45
Cornstalks + inorganic salts	329	544	1.08	5.88	19	27
Cow manure	324	553	1.14	6.31	21	25

*Increase in plant growth due to treatment.

Corn series.—The results of the corn series were similar to those above, with the exception that the complete fertilizer was slightly more and the cornstalks compost slightly less beneficial.

GREENHOUSE TESTS OF THE LEAVES + TIMOTHY HAY COMPOST

The leaves + timothy hay compost was started and consequently completed later than the others. To determine its value special greenhouse tests were run. The results as a whole indicated that this product could be considered only as a soil conditioner and not a fertilizer. When it is used, it should be reinforced with fertilizer or the original materials should be supplemented with chemicals when used for composting.

SUMMARY

Several artificial manures were prepared from organic residues by the composting process. At various intervals during decomposition,

samples of the composts were analyzed for moisture, ash, ammonia, nitrate, total nitrogen, pH, and approximate chemical composition. The temperature of each compost was recorded at frequent intervals and the dry weight of the organic material lost during decomposition was determined. The quality of the artificial manures produced was studied by greenhouse and field tests, which were supplemented by laboratory nitrification and fungus culture tests. The results are summarized as follows:

1. The fatty and waxy substances, water-soluble organic matter, hemicelluloses, and cellulose underwent extensive decomposition in all the composts.

2. The extent of the lignin decomposition depended greatly upon the chemical nature of the plant materials used. The lignins in straw and cornstalks decomposed only slightly, whereas those in timothy hay, clover hay, and cow manure showed great decomposition.

3. The crude protein increased greatly in the oat straw + inorganic salts and the cornstalks + inorganic composts and slightly in the oat straw + clover hay compost. It decreased slightly in cow manure and lowmoor peat + timothy hay composts and to a considerable extent in the leaves + timothy hay compost.

4. For every 1,000 pounds of organic residue used for composting, approximately 1 ton of artificial manure was produced.

5. The greenhouse and field studies demonstrated the production from cornstalks of a high quality artificial manure comparable to composted cow manure within a period of 3 months. Good quality products were prepared within 4 to 6 months from cereal straw. Resistant materials, such as salt-grass hay and woody residues, required much longer periods for proper decomposition. Tree and shrub trimmings and other woody materials should not be mixed with ordinary plant refuse because of the slowness with which they decompose. Such products should be built into a special manure pile and be allowed to decompose for a longer time. Composts from peat and leaves should be considered only as soil conditioners. They will, however, make high quality manures if reinforced with inorganic fertilizer. The residual effect of the composts produced from cow manure, cornstalks, and cereal straw was much greater than that of inorganic fertilizer.

6. Nitrification and fungus culture tests confirmed the results of the greenhouse and field tests.

LITERATURE CITED

1. ALBRECHT, W. A. Artificial manure production on the farm. Mo. Agr. Exp. Sta. Bul. 258. 1927.
2. ASSOCIATION OF OFFICIAL AGRICULTURAL CHEMISTS. Official and Tentative Method of Analysis. Washington, D. C. 1935.
3. BROWN, P. E., and SMITH, F. B. The production of artificial manure from oat straw under controlled conditions. Jour. Amer. Soc. Agron., 21:310–322. 1929.
4. GALVEG, N. C., and ROMERO, I. A. A study on the preparation of compost from rice straw. Philippine Agr., 29:753–765. 1941.
5. GREENSTREET, V. R. Artificial manure. Malayan Agr. Jour., 16:124–203. 1928.
6. HALVERSEN, W. V., and JORGENSON, E. F. Production of artificial manure by fermenting straw. Jour. Amer. Soc. Agron., 19:577–584. 1927.

7. HUTCHINSON, H. B., and RICHARDS, E. H. Artificial farmyard manure. Jour. Min. Agr., 28:398–411. 1922.
8. LEMMERMANN, O., and GERDUM, E. Die Herstellung von "Künstlichenstalldünger". Ztschr. Pflanz. Dung. Bodenk., 6:481–485. 1927.
9. NIKLAS, H., POSCHENRIEDER, H., and TRISCHEN, D. T. Die Kultur des Schimmelpilzes *Aspergillus niger* zur biochemischen Bestimmung der Kali und Phosphorsäuredüngebedürftigkeit der Boden. Ernähr. Pflanze, 26:97–103. 1930.
10. PRESCOTT, T. A., and PIPER, C. S. Synthetic farmyard manure. Jour. Dept. Agr. Soc. Austr., 30:738–742. 1927.
11. SHIRKHANDE, T. G. Determination of ammoniacal and nitrate nitrogen in decomposed plant material. Jour. Ind. and Eng. Chem., 13:187. 1941.
12. SMITH, F. B. The rate of decomposition of some artificial manures. Proc. Iowa Acad. Sci., 36:69–73. 1929.
13. ———— and BROWN, P. E. The decomposition of straw in the production of artificial manure. Iowa State College Jour. Sci., 8:409–413. 1934.
14. TRUOG, E., and FRED, E. B. The *Aspergillus niger* method of measuring available potassium in soil. Soil Sci., 35:209–278. 1933.
15. TURK, L. M. Synthetic manure production in Michigan. Mich. Agr. Exp. Sta. Circ. Bul. 157:1–11. 1936.
16. WAKSMAN, S. A., and GERRETSEN, F. C. Influence of temperature and moisture upon the nature and extent of decomposition of plant residue by microorganisms. Ecology, 12:33–60. 1931.
17. ———— and NISSEN, W. On the nutrition of the cultivated mushroom, *Agaricus compestris*, and the chemical changes brought by this organism in the manure compost. Amer. Jour. Bot., 19:514–537. 1932.
18. ———— and RENGER, C. A. Artificial manure for mushroom production. Mycologia, 26:38–45. 1934.
19. ———— and STEVENS, K. R. A system of proximate chemical analysis of plant material. Ind. and Eng. Chem., Anal. Ed., 2:167–184. 1930.
20. ————, TENNEY, F. G., and DIEHEM, R. A. Chemical and microbiological principles underlying the transformation of organic matter in the preparation of artificial manures. Jour. Amer. Soc. Agron., 21:535–546. 1929.

FURTHER INTERPRETATIONS OF FIELD TESTS BY THE UNIVERSAL YIELD DIAGRAM[1]

O. W. WILLCOX[2]

THIS paper presents two field tests as further illustration of inferences that may be drawn through application of the universal yield diagram.

One of these tests relates to the use of nitrogen as ammonium sulfate with sugar cane on the Umfolozi Flats, Natal, South Africa. The data were kindly placed at the writer's disposal by H. H. Dodds, Director of the Experiment Station of the South African Sugar Association, Mount Edgecombe, Natal, South Africa. Previous tests on these Flats had failed to reach significance on account of soil variability, and it was decided to lay down a test with three treatments with nitrogen on 1/10–acre plots in 24 replications in the hope that the larger numwould result in better significance.

The experimental field consisted of four large blocks, I, II, III, and IV, each comprising two Latin squares; and each square contained nine plots. The curves of the yields of cane from each block are shown in Fig. 1, together with a curve representing total cane yield from all blocks and a curve representing total sugar yield. To economize space only the block averages and the general averages are reproduced here (Table 1). To obtain "unit yields" that come within the scale of the

TABLE 1.—*Cane and sugar yields, Umfolozi experiment.*

Ammonium sulfate, lbs. per acre	Equiv. baules of N	Block yields, tons per acre								General averages, tons per acre	
		I		II		III		IV			
		Cane	Sugar	Cane	Sugar	Cane	Sugar	Cane	Sugar	Cane	Sugar
0	0.	34.50	5.66	34.54	5.62	31.04	5.07	30.07	4.84	32.5	5.30
400	0.385	37.16	6.07	34.76	5.54	35.81	5.59	34.24	5.35	35.5	5.64
800	0.770	37.13	6.01	38.28	6.07	37.43	6.06	34.50	5.34	36.8	5.87

diagram, the average yields of cane were multiplied by 0.4 and the sugar yields by 2. These unit yields are fitted in the diagram in the previously described manner, namely, by first marking the unit yields as pencil dots on transparent paper in proper horizontal and vertical relation on the same scale as the standard diagram, and then moving the transparent paper over the face of the diagram until imaginary lines joining the points transect the fewest curves. The weighted median of the transected curves is taken as the normal curve that comes closest to making a fit. The number (underlined numerals in Fig. 1) of the median curve is taken as the "*A* value" of the soil

[1]Received for publication August 30, 1943.
[2]Consulting Agrobiologist, Ridgewood, N. J.

of the block with respect to nitrogen, and represents A in the Mitscherlich-Baule yield equation

$$\log_{10}(A - y) = \log_{10} A - 0.301x;$$

x on the horizontal axis represents Baule units of 223 pounds of nitrogen each. For convenience a Baule unit is called simply a baule(s).

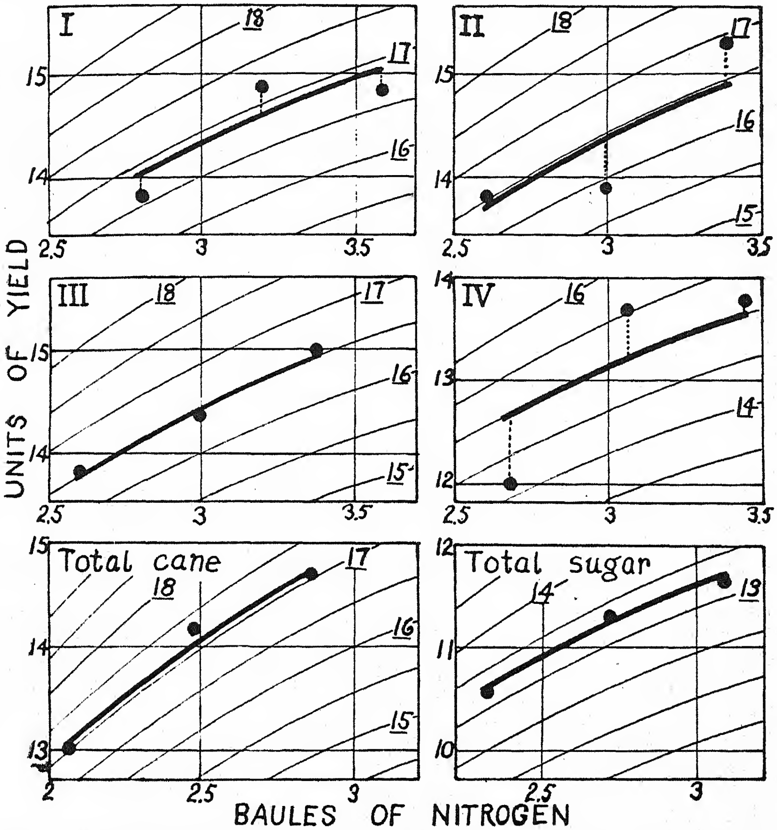


FIG. 1.—Umfolozi field test with ammonium sulfate on sugar cane. Reported by H. H. Dodds (private communication).

Inspection of Fig. 1 indicates that soil variability is in evidence on blocks I, II, and IV, resulting in some scattering of the points. On block I the spread of the A values between the points is between 16.6 and 17.2; the weighted median is $A = 16.8$. On II the range is between 15.8 and 16.8, median 16.4. On block III, which of the four blocks makes the closest approach to normality, the range is 16.45 to 16.55, median 16.05, which is a close fit. On block IV, where the departures from normality are largest, the range is 14.2 to 15.5, median 15.0. On the other hand, when the general averages of all the cane

yields are fitted in the diagram, the range is between 17.05 and 17.35, median 17.2, which may be regarded as a good fit.

The over-all result is that, whereas three of the experimental blocks fail to reach statistical significance the total cane yields conform closely to the normal yield equation. The normality of the increases of total cane yields is corroborated by the curve of total sugar yields, which fit closely curve $A = 13.3$, with statistical odds of better than 19:1. The object sought, namely, to achieve statistical significance by enlarging the number of replications, has thus been attained, and in this case it turns out that statistical significance virtually coincides with the Mitscherlich-Baule yield equation, which this writer accepts as the expression of agrobiologic normality.

If blocks II and IV, for example, are regarded as separate three-treatment, six-replicated experiments, and independent field tests of this scope are commonly made, they may be taken to illustrate some differences between the statistical and the agrobiologic approach to the interpretation of field tests with plant nutrients. The experimental statistician looks for "significance", using the "t" test as a criterion. The agrobiologist looks for trends. His faith in trends is grounded on the indisputable fact that when available nitrogen is added to an otherwise normal soil that is deficient in this plant nutrient, an increase of yield will infallibly ensue, assuming, of course, that the operator is competent and commits no errors. Any appreciable increase that is attested by the weigh scales is accepted at its face value. From the agrobiologic standpoint it does not matter if one individual plot yields more or less than another under the same treatment; regardless of soil variations, the mean of the individual plot yields is taken as the true average yield from the treatment, and without any statistical discount is marked on the standard yield diagram. Detailed reasons for disregarding soil variations in field tests with plant nutrients while accepting analysis of variance for certain other categories of field experiments have been set forth in another place (2).[3]

As for block II, it will be observed that the lower addition of nitrogen showed practically no increase over the controls, while the higher addition gave an apparent increase of 3.74 tons. On block IV the lower addition gave an increase of 4.17 tons over the controls, which was scarcely bettered by the higher addition. In spite of the scattering of the points, the upward trend of the yields is plainly visible. The question may be put, Are the increases deceptive or real? From the statistical side, a mere glance at the discordant averages forestalls expectation of significance. On the other hand, an agrobiologist, having in mind that no competent operator could make experimental errors amounting to 3 or 4 tons of sugar cane, and mindful that on agrobiologic grounds discrepancies in yields due to soil variability in field tests with plant nutrients are not classifiable as "error", will see no good reason for refusing to regard the visible trends as real. What it amounts to is that situations which fill an experimental statistician with misgivings may inspire a practical agrobiologist to confident action.

[3]Figures in parenthesis refer to "Literature Cited", p. 392.

Viewing this experiment in its entirety, it is evident that in spite of marked soil variability in the constituent blocks, the A value of the whole field in respect of nitrogen is $17.2 / 0.4 = 43.0$ tons of cane to the acre. The average yield of 36.8 tons given by the higher addition of nitrogen might have been increased by about 7 tons if more nitrogen had been added. Beyond this item of agronomic information there are wider implications. From this position of the initial yield on the curve of total cane yields it is seen that the untreated soil already contained an average of 2.02 baules of nitrogen to which the operator added 0.77 baule, making a total of 2.97 baules (622 pounds per acre). This amount of available soil nitrogen, by calculation with the Mitscherlich-Baule yield equation, is sufficient to produce 85.4% of a maximum crop if adequately supported by the other factors of plant growth. The known yielding abilities of sugar cane varieties grown in South Africa are of the order of at least 120 tons to the acre; 85.4% of this figure is 101.4 tons, which is nearly three times the 36.8 tons obtained in this experiment. It is worthy of note that the curve of total sugar yield, which usually is very sensitive to an excess of nitrogen, shows no visible sign of unbalanced nutrition. These considerations give the operator a hint to regard the nitrogen factor as well in hand and to get after other factors that are denying the cane plants the opportunity of using the given supply of nitrogen to produce 100 tons if not more.

The other field test selected to illustrate the agrobiologic approach is taken from a paper by Scarseth (1), who reports a compound test conducted by H. L. Cook with corn on Crosby silt loam in Indiana. This work embraced a test with four treatments with nitrogen at three levels of potash. For diagramming, the pounds of fertilizer used are converted into baules (a baule of potash is 82 pounds, of nitrogen 223 pounds) and the bushels of corn are divided by 7. The data then appears as in Table 2.

These data fit into the standard yield diagram as shown in Fig. 2. It is seen that the first, second, and fourth yields at the first potash level (lowermost heavy curve) fit closely on normal curve $A = 19$, but the third yield (denoted by star in Fig. 2) is abnormally high. At the second potash level the first yield (no added nitrogen) is abnormally low compared with the three others, which fall regularly on curve $A = 23$. An analogous situation exists at the third potash level. The plots with no added nitrogen have again produced only a small increase in spite of the presence of 1.22 baules of added potash, while the three additions of nitrogen give regularly spaced yields that fall on curve $A = 24$.

Ignoring the abnormalities for the moment, it is clear that this field as a whole reacts normally to nitrogen at all levels of potash fertilization. The normal aspect of the lowermost heavy curve indicates that this portion of the field, which received no added potash, has an A value of 19 yield units. This means that if addition of nitrogen were continued to the limit, and if no depression phenomena intervened the normal ultimate yield in this series would be $19 \times 7 = 133$ bushels. Similarly, the normal A value in respect of the same increments of nitrogen in the second potash series would be $23 \times 7 = 161$ bushels and in the third series it would be $24 \times 7 = 168$ bushels.

TABLE 2.—*Cook's nitrogen-potash test, reported by Scarseth.*

Nitrogen added		Potash used		Yields, bu. per acre	
Lbs. per acre	Baules	Lbs. per acre	Baules	Reported	Divided by 7
		First Potash Level (No Added Potash)			
0	0	0	0	29.5	4.21
21	0.0941	0	0	36.3	5.18
42	0.1882	0	0	49.4	7.05
84	0.3764	0	0	52.8	7.54
		Second Potash Level			
0	0	50	0.61	30.8	4.40
21	0.0941	50	0.61	49.4	7.05
42	0.1882	50	0.61	56.2	8.05
84	0.3764	50	0.61	68.1	9.73
		Third Potash Level			
0	0	100	1.22	33.8	4.83
21	0.0941	100	1.22	50.1	7.16
42	0.1882	100	1.22	59.3	8.47
84	0.3764	100	1.22	71.8	10.26

To return to the three abnormalities that show up in Cook's work, from the agrobiologic standpoint these abnormalities must be accepted at their face values and duly fitted into the quantitative picture. It is to be presumed, until further experience shows the contrary, that when the operations on this experimental field are magnified to a plantation scale, the discounts or premiums imposed on the ultimate normal yields by these abnormalities will, at most, be proportionally no greater than appears in the experimental results. Thus, the yield with no added nitrogen at the second potash level falls on curve 17 while the other three fall on curve 23. The weighted median A value is 21.5, which makes the A value of this portion of the field 150.5 bushels instead of 161. In the series at the third potash level the abnormally low yield falls on curve 18, which makes the real A value under these circumstances 157.5 instead of 168 bushels. On the other hand, the abnormally high yield from the second nitrogen addition in the series without added potash falls on curve 22, while the three others are on curve 19. The real A value under these circumstances becomes 20.1, or $20.1 \times 7 = 140.7$.

Agrobiologically interpreted, the gist of this experiment is that yields of corn on the soil represented by this experimental field may be made to approach 157.5 bushels by the free use of nitrogen on the third potash level. This expectation, however, is subject to the contingency that yield depression due to nutritional unbalance may occur when larger additions of nitrogen are made (3). Whether such a barrier will be encountered must be determined by experiment. If encountered, the agronomist may then consider measures for removing it. Further, since the yield curve is asymtotic, economic considerations may impose a limit more or less short of the ultimate A value.

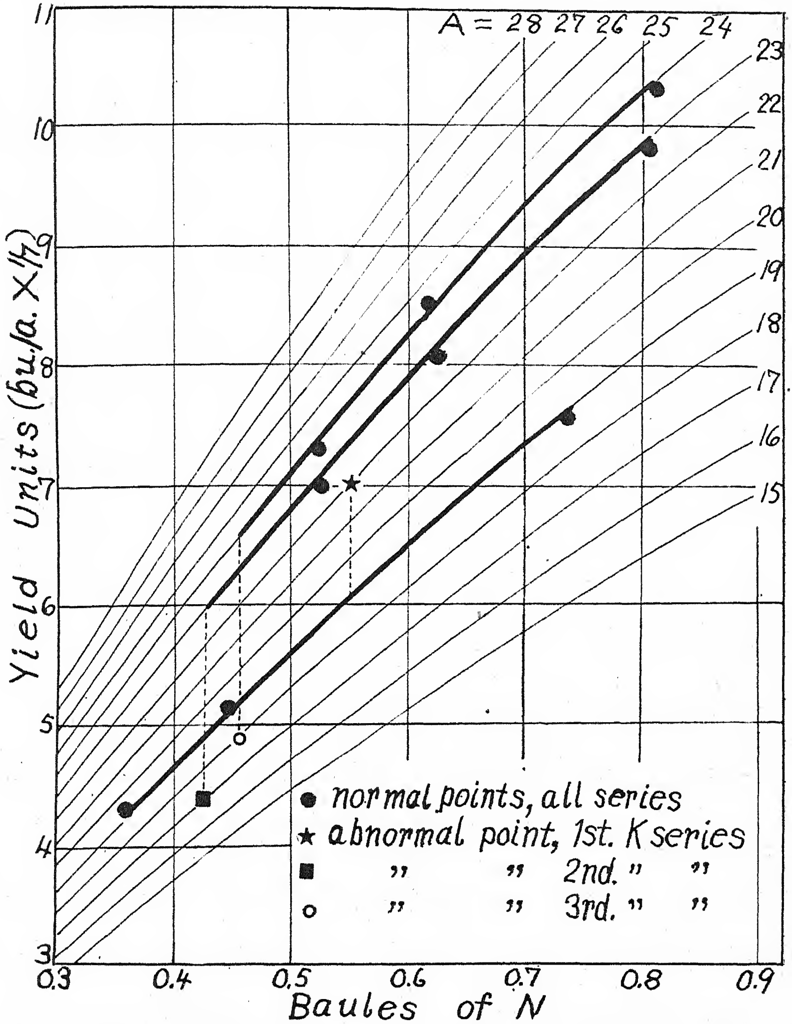


FIG. 2.—Field test with nitrogen and potash on corn by H. L. Cook. Reported by George D. Scarseth (1).

CONCLUSIONS

It will be understood from these and other published examples (4) that the universal yield diagram interprets the result of a field test with a plant nutrient in terms of *A* values, or the ultimate possible yield obtainable from the nutrient under given circumstances. Through use of the diagram the test becomes something more than merely finding that a certain amount of the nutrient will "pay" under the economic circumstances of the moment. The experimenter obtains a normal yield curve from which, in the first instance, he may easily

compute the economic limit for any given economic circumstances. In the second instance he may have his eyes opened to broad opportunities. For example, in the Umfolozi experiment Dodds found that the amounts of nitrogen employed gave uneconomic returns. Beyond that, it was demonstrated that on this field large amounts of nitrogen in the soil gave an agrobiologically normal yield curve and hence nitrogen was not the limiting factor in keeping down cane and sugar yields. This discovery amounted to an invitation to look for the other circumstances that were preventing cane varieties of known great yielding ability from approaching 120 tons. It may take some hard work to break down the barriers to such yields. However, such work is what experiment stations are supposedly for, although the writer has been assured by an agronomy professor that it is of no practical interest to know that corn, under the most favorable conditions, may give a perultimate yield of 250 bushels (field weight) to the acre.

Considering the enormously important role of food production in the world's economy, the writer gives it as his opinion that agronomists and schools of agronomy will not be fully discharging their public responsibilities until they adjust their sights to *A* values, and learn to work from *A* values toward the perultimate values.

LITERATURE CITED

1. Scarseth, George D. Value and limitations of diagnosing plant nutrient needs. Better Crops With Plant Food, May, 49. 1943.
2. Willcox, O. W. A critique of field experiments with plant nutrients. Amer. Fert., 95, No. 5:5–7, 26; No. 6:5–7, 24. 1941.
3. ————. Yield depression effect of fertilizers, and its measurement by the universal yield diagram. Jour. Amer. Soc. Agron., 36:20–31. 1944.
4. ————. Interpretation of Olsen and Shaw's field tests by the Mitscherlich-Baule theorem and the universal yield diagram. Jour. Amer. Soc. Agron., 35:454–459. 1943.

REVEGETATION IN THE TALL GRASS PRAIRIE REGION[1]

Donald R. Cornelius[2]

THE tall grass prairie originally covered much of the eastern halves of Oklahoma, Kansas, Nebraska, and the Dakotas; also western Missouri and Iowa and part of Illinois and Minnesota. Much of this land was plowed for cultivation, except where it was too steep or rocky, as in the Flint Hills of Kansas or the Osage country of Oklahoma.

So long as the production of the cultivated crops was profitable, there was no desire to retire any of the cultivated land to grass. Within the past decade, however, drouth, the effects of erosion, depletion of soil fertility, economic conditions, and labor shortage have started a trend toward retiring some of the cultivated upland in this section to grass for pasture or hay. Introduced grasses are commonly recommended for the eastern part of the tall grass prairie, but farther west and south native species withstand the environmental conditions better than any grasses thus far introduced. Since the use of these native species for revegetation plantings is very recent, little experimental work has been done with reference to methods of establishment on cultivated land.

MATERIALS AND METHODS

A 20-acre tract of cultivated upland approximately 9 miles southwest of Manhattan, Kans., was selected for experimental planting. The soil, residual from limestone, is Idana silt loam. Erosion had been moderate to severe with gully formation starting. Approximately one-half of the top soil had been removed by erosion, leaving only 4 inches above the B horizon and less where gullies had started. The slope is approximately 5%.

In 1940 a grass seed mixture was planted which included the following species: *Andropogon furcatus*, big bluestem; *Andropogon scoparius*, little bluestem; *Bouteloua curtipendula*, side-oats grama; *Panicum virgatum*, switchgrass; *Bouteloua gracilis*, blue grama; and *Buchloë dactyloides*, buffalo-grass. That seeded in 1941 and 1942 did not contain seed of the last two species, but had *Sorghastrum nutans*, Indian-grass, added to the first four species listed. The amount of seed for each species making up the mixtures, expressed as rate in pounds per acre for each of the three years, is given in Table 1.

Four types of seedbed were tested. Sudan grass stubble, millet stubble, and plowed oat land were used in 1940, 1941, and 1942. Sweetclover stubble was used in 1941 and 1942. Plots were 1⅓ acre in size. A grain drill was used in planting all of the crops which preceded the grass planting. The Sudan grass and millet grown in 1939 to provide stubble for the 1940 grass planting were injured by chinch bugs. The Sudan grass was especially damaged and no seed was produced, although the plot was not clipped. All of the plots grown in 1940 to provide stubble for the 1941 grass plantings were clipped high in the summer to prevent seed production. All clipped material was left on the land. The plots grown in 1941 to provide stubble for 1942 were not clipped and seed was produced. Considerable volunteer Sudan grass emerged with the grass seedlings in 1942 but volunteer millet gave no trouble. The volunteer sweetclover emerged before grass planting time and was controlled by double disking before planting the grass seed. In all other cases the land was lightly disked in late spring just before the grass was to be planted

[1]Contribution from the Nursery Division, Soil Conservation Service, U. S. Dept. of Agriculture, Manhattan, Kans. Received for publication September 10, 1943.

[2]Associate Agronomist.

to kill weeds which had started to grow, and the areas were cultipacked before and after planting. The oats stubble was plowed under each year in late July after the crop of grain had been harvested. The land was permitted to lie rough over winter without further tillage.

TABLE 1.—*Rate of planting, purity, germination, seed per pound of pure seed, viable seed per square meter, seedlings per square meter, and percentage of viable seed producing seedlings, 1940, 1941, 1942, and summary for the 3 years.*

Species	Lbs. of seed per acre	Purity, %	Germination, %	No. seed per lb. pure seed	Viable seed per sq.m.	Seedlings per sq.m.	Viable seed producing seedlings, %
			1940				
A. furcatus	15.00	18.6	29.0	143,918	28.8	5.33	18.51
A. scoparius	15.00	38.1	39.0	224,504	123.6	16.17	13.08
B. curtipendula	10.00	15.9	77.0	565,230	171.0	35.43	20.72
B. gracilis	1.00	24.5	67.0	822,700	33.4	0.13	0.39
B. dactyloides	0.67	32.0	15.0	55,182	0.4	0.00	0.00
P. virgatum	7.33	28.2	47.5	314,741	76.4	26.10	34.16
S. asper	1.00	84.7	89.0	408,988	76.2	5.70	7.48
Total	50.00				509.8	88.86	17.43
			1941				
A. furcatus	17.5	59.2	69.0	125,259	221.3	3.35	1.31
A. scoparius	15.0	66.0	47.5	452,184	525.4	4.85	0.92
B. curtipendula	6.5	22.0	61.0	577,818	124.5	11.55	9.28
P. virgatum	5.0	93.6	79.0	368,388	314.6	6.70	2.13
S. asper	2.5	69.7	46.0	408.988	81.0	—	—
S. nutans	3.5	58.8	58.5	166,804	49.6	0.50	1.01
Total	50.0				1,316.4	26.95	2.05
			1942				
A. furcatus	9.60	37.7	64.0	125,259	71.7	12.2	17.02
A. scoparius	3.71	90.1	10.5	452,184	39.2	1.5	3.83
B. curtipendula	3.49	26.3	73.5	456,724	76.1	8.3	10.91
P. virgatum	2.84	95.2	56.5	300,447	113.4	10.55	9.30
S. asper	1.31	82.9	80.5	408,988	88.3	1.35	1.53
S. nutans	1.90	97.3	46.5	167,163	35.5	14.70	41.41
Total	22.85				424.2	48.60	11.46
			Summary for 3 Years				
A. furcatus	—	—	—	—	107.3	6.96	6.49
A. scoparius	—	—	—	—	229.4	7.51	3.27
B. curtipendula	—	—	—	—	123.9	18.43	14.88
P. virgatum	—	—	—	—	168.1	14.45	8.59
S. asper	—	—	—	—	81.8	2.35	2.87
S. nutans	—	—	—	—	42.6*	7.60*	17.86

*Averages for 2 years; otherwise, averages under summary are for 3 years.

All of the plots were laid out on the contour and the oat plots were plowed on the contour, thus reducing sheet erosion during the winter when the area was not covered by vegetation. Wind erosion is not a problem in this area.

In 1940 the grass seed was hand broadcast, and in 1941 and 1942 processed seed was planted with a grain drill, seedings being in late April each year. Weeds

were clipped about the middle of June and August at a height of about 4 inches to avoid injury to the perennial-grass seedlings. The number of grass seedlings per meter-quadrat was determined in September, 10 meter-quadrats per plot being counted in 1940 and 5 meter-quadrats per plot in 1941 and 1942.

WEATHER CONDITIONS

Climatic conditions in 1940 were favorable for emergence and growth of the seedlings in April, May, and June, and, as a consequence, greater numbers of seedlings per unit area were obtained that year than in 1941 or 1942. Rainfall distribution was very good during the spring of 1940, but July was a dry month with only 0.38 inch of precipitation. The grass seedlings had become sufficiently well established to withstand the dry period, however. The spring of 1941 was dry, which prevented many seedlings from becoming established. The summer of 1941 was not as dry as 1940. Precipitation for July 1941 was 1.29 inches, or 2.87 inches below normal, which was not favorable to good seedling development. The season of 1942 presented very satisfactory growing conditions. Precipitation for the period April to July, inclusive, was 21.44 inches, or 5.24 inches above normal. Weed competition was rather severe, as is usual in wet years. Apparently the yearly total precipitation had but little influence on establishment of grass stands, but rather the distribution of precipitation during seedling establishment is the important factor. The critical months for spring-sown species are from April to August.

EXPERIMENTAL RESULTS

STUBBLE MULCH

Millet produced slightly more pounds of litter as determined at grass-seeding time than Sudan grass. The Sudan grass provided a more desirable type of cover, owing to the leafy basal growth produced, especially after clipping. Millet stubble was coarser and failed to produce any aftermath when clipped in the summer. There was no significant difference in the number of seedlings established per square meter under either of these treatments. Table 2 gives the amount of litter on the plots at grass-seeding time and the number of seedlings established under the different treatments.

Some of the most satisfactory stands were obtained following a crop of oats. This was especially true in 1940 and 1942, although the establishment on this seedbed was not as good as with Sudan grass or millet stubble in 1941, as shown in Table 2. Seedlings on the oat land were more vigorous. The difference in vigor of the grass plants under the different treatments was also apparent the second year, as is shown in Fig. 1 compared to Fig. 2.

Sweetclover was found to be the least satisfactory in the type of stubble produced and in the number of seedlings established per square meter. This crop produced a smaller amount of stubble than Sudan grass or millet and the stubble was coarse and undesirable as a mulching material. Also, the growth of crabgrass was greater following sweetclover and gave more competition to the small native grass seedlings. This increased growth of crabgrass occurred in spite of the effective control of it the previous year by the dense vigorous growth of sweetclover preceding the grass planting. Two years were required to obtain sweetclover stubble since it is a biennial. The project was started in 1939, therefore sweetclover stubble could only be used for the 1941 and 1942 grass plantings, whereas 3 years' results were obtained with the other crops.

TABLE 2.—*Amount of air-dry stubble on the surface of the ground at grass-seeding time and the number of perennial grass plants in September after seeding, 1940 to 1942, inclusive.*

Preceding crop	Pounds of mulch per acre at seeding time*	Grass plants per meter†
1940		
Oats	—‡	99.7
Sudan grass	2,777	84.0
Millet	2,800	92.8
1941		
Oats	—‡	23.8
Sudan grass	2,951	45.4
Millet	4,060	33.4
Sweetclover	2,839	5.4
1942		
Oats	—‡	70.8
Sudan grass	4,792	50.8
Millet	4,920	36.8
Sweetclover	1,919	42.2

*Average for 3 meter-quadrats in 1940 and 5 meter-quadrats in 1941 and 1942.
†Average for 10 meter-quadrats in 1940 and 5 meter-quadrats in 1941 and 1942.
‡Oats stubble plowed under the preceding autumn.

ESTABLISHMENT OF SPECIES

Certain species were found to be more easily established than others. This was determined by the ratio of

$$\frac{\text{seedlings established per square meter}}{\text{viable seed planted per square meter}},$$

expressed as percentage. As shown in Table 1, *Bouteloua curtipendula, Sorghastrum nutans, Panicum virgatum*, and *Andropogon furcatus* were the most easily established. *Andropogon scoparius* and *Sporobolus asper* were not established as readily. *Bouteloua gracilis* and *Buchloë dactyloides* were included only in 1940. These short grasses do not withstand the shading and competition of the weeds occurring under conditions of greater rainfall. They survive under such conditions only when top growth is removed by close clipping or grazing.[3]

The relatively unfavorable season of 1941 lowered the percentage establishment of all species as compared with 1940 or 1942. *Bouteloua curtipendula* was not affected nearly as much as the other species. It appears to have more drouth resistance than the true tall grass species used in this test. The year in which the highest per cent of grass seeds produced seedlings was 1940, with 17.43%; 1941 gave only 2.05%, and the more favorable 1942 gave 11.46%. The numbers

[3]ALDOUS, A. E. Effect of different clipping treatments on the yield and vigor of prairie grass vegetation. Ecology, 11:752–759. 1930.

WEAVER, J. E., and CLEMENTS, F. E. Plant Ecology. New York:McGraw-Hill Book Co. 1929. (Page 463).

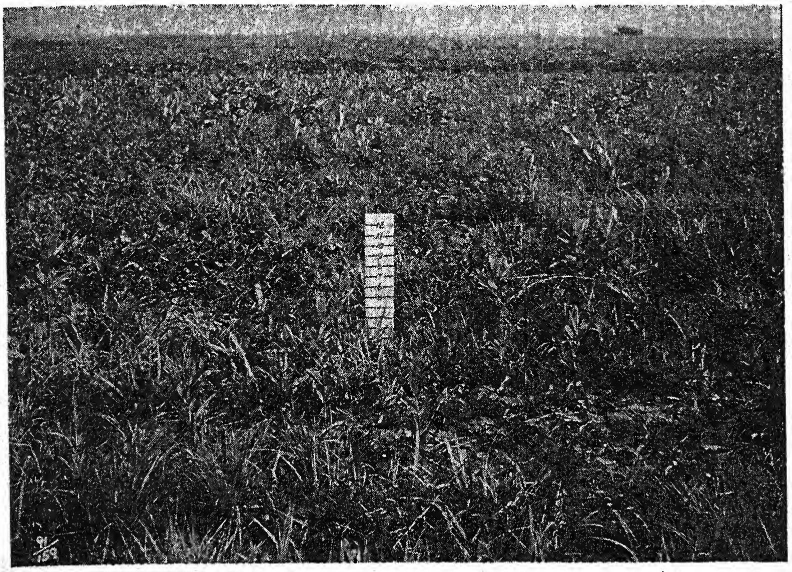


FIG. 1.—Native-grass mixture planted April 1940 in Sudan stubble (disced and cultipacked). Photographed May 10, 1941.

of viable seeds were determined by standard seed laboratory tests for purity, germination, and number per pound, as given in Table 1.

FIG. 2.—Native-grass mixture seeded April 1940 on oat-stubble land which had been summer plowed in 1939. Photographed May 10, 1941.

WEED COMPETITION[4]

During the first season of establishment, all of the plots were very weedy. Crabgrass, *Digitaria sanguinalis*, was the most abundant. Three other annual weedy grasses occurred in the following order: Green foxtail, *Setaria viridis;* fall panicum, *Panicum dichotomiflorum;* and witchgrass, *P. capillare*. These annual weedy grasses emerged about the same time as the perennial native grass seedlings, but they made more rapid growth in the seedling stage. They were able to compete very severely for moisture, nutrients, and light, and greatly retarded growth of the desirable grasses the first year of establishment, but they were not of any importance the second year.

Other weeds which occurred occasionally in the plantings were as follows: Brown-eyed Susan, *Hibiscus trionum;* evening primrose, *Oenothera biennis;* common sunflower, *Helianthus annuus;* green pigweed, *Amaranthus retroflexus;* mare's-tail, *Erigeron canadensis;* prickly lettuce, *Lactuca serriola;* and erect knotweed, *Polygonum erectum*. These were controlled rather effectively by two summer clippings. When left unclipped the principal damage from these weeds was shading the grass seedlings. With each planting, the first year the weeds were clipped when they started shading the small perennial grass plants, about the middle of June, and again in August.

Each fall, weeds were more in evidence than the perennial grass plants on the newly planted areas, but the perennial grass plants always had the advantage the second season. The plots were clipped but once the year after seeding, and although it was not feasible because of plot arrangement, it would have been possible to graze lightly the second year without retarding establishment.

Grass plantings frequently are plowed under at the end of the first year beause weeds are more noticeable than the perennial grass seedlings. A careful examination should be made before plowing because sufficient grass seedlings may be present, although they are small and inconspicuous the first year compared to annual weeds. Under eastern Kansas conditions, an average of 20 plants per square meter will usually produce a satisfactory sod in 3 years. A greater number of seedlings will hasten the establishment of a sod, but 2 years are usually required under the best conditions to approach the density of the original prairie.

PLANTING RATE

Weber[5] found that native grass seed could be processed through a special hammer mill and recleaned by a fanning mill to remove pubescence and chaffy material and permit more satisfactory planting with an ordinary grain drill. After drilling seed processed in this manner in 1941 at the same rate as hand broadcasting unprocessed seed in 1940, it was found that the planting rate was greater than needed. As shown in Table 1, the 50- pound rate of unprocessed seed in 1940 gave 510 viable seeds per square meter and the same rate in

[4]Weed names are according to "Weeds in Kansas", by F. C. Gates in report of the Kansas State Board of Agriculture, 60, No. 243. 1941.

[5]WEBER, G. L. A method of preparing some native grass seeds for handling and seeding. Jour. Amer. Soc. Agron., 31:729–733. 1939.

1941, using processed seed, gave 1,316 viable seeds per square meter, which was more than necessary and wasteful of seed. Reducing the rate to 22.85 pounds of processed seed per acre in 1942 gave 424.2 viable seeds per square meter which is considered to be satisfactory.

ARTIFICIAL SEEDING VS. NATURAL REVEGETATION

On the upper slope adjoining the area used for these seeding tests was an area of approximately 1 acre that had lain abandoned from cultivation for the 18 years previous to 1940. The soil type was similar to that of the seeded area. Natural revegetation had been favored by the spread of seed from a fence row along the south side of the area. The fence row had never been plowed and had many plants of all of the species in the mixture used for the seeding experiments. This area which had been revegetated under natural conditions during the 20 years of abandonment had developed a basal density approaching that of native tall grass prairie, although the species were not present in the same relative abundance. Charted quadrats revealed a high percentage of three perennial grasses, *Sorghastrum nutans*, *Bouteloua curtipendula*, and *Sporobolus asper*, and two perennial weeds, many-flowered aster, *Aster ericoides*, and blue sage, *Salvia pitcheri*. A lower percentage of the two most desirable perennial grasses, *Andropogon furcatus* and *A. scoparius*, was found in comparing the area of natural revegetation with either native prairie or the seeded areas.

The area seeded in 1940 had approximately the same basal cover in 1942 as the area which had been abandoned 18 years previous to 1940. The abandoned area had passed through the weedy-annual stage of about 6 years and the weedy-perennial stage of of 6 to 10 years and was just entering the desirable perennial-grass stage in 1942. This area was favored for natural revegetation over most abandoned areas in two ways, *viz.* (a) close proximity of a natural seed-producing area on the windward and upper side, and (b) protection from grazing. A better choice of species was obtained on the seeded area than occurred under natural revegetation.

SUMMARY

1. Although the use of native species to revegetate land retired from cultivation is recent, satisfactory methods of establishment are being developed.

2. In 1940, 1941, and 1942 near Manhattan, Kans., a mixture of native grasses, including big bluestem, little bluestem, side-oats grama, switchgrass, Indian-grass, and tall dropseed, was planted on upland retired from cultivation.

3. Better establishment of grass seedlings was obtained 2 years out of 3 by planting on land which had been in oats the previous year. The land was plowed in July and a firm seedbed was prepared at grass-seed planting time in late April of the following spring. Sudan stubble and millet stubble grown the previous year and left unplowed were fairly satisfactory for grass planting. Sweetclover stubble was the least satisfactory of the stubble mulches tested.

4. Side-oats grama, Indian-grass, switchgrass, and big bluestem gave better establishment in relation to viable seed planted than little bluestem or tall dropseed.

5. Weed competition was severe throughout the seedling year. Crabgrass was especially troublesome. Two clippings reduced weed competition sufficiently to permit grass seedlings to survive the first year. The perennial grasses could effectively compete with the weeds the second year, when only one clipping was required.

6. As compared with natural revegetation, these tests showed that approximately the same basal cover may be obtained the second year after establishment by seeding as in 20 years of natural revegetation on abandoned land. A much better choice of species can be obtained on the seeded areas.

THE FOOD CONTENT OF FORAGE CROPS AS INFLUENCED BY THE TIME OF DAY AT WHICH THEY ARE CUT[1]

Otis F. Curtis[2]

DURING the growing period the digestible food content, the total dry matter and the relative composition of the various constituents of the tops of forage crops will show a change from morning to afternoon and from afternoon to the next morning. It is obvious that such changes will almost inevitably occur because the manufacture of carbohydrate from the raw materials, carbon dioxide and water, occurs only while the plant is exposed to light, therefore any gain in total food content will occur only while exposed to light. There must be some loss from the plant as a whole during darkness because of respiration. The loss of digestible food content from the shoots at night results partly from this respiration, partly from utilization in growing parts of the shoot, and partly from transport to roots or other underground portions. The amount of gain during the day will be greatly influenced by several factors, especially the light conditions, and the amount of loss and transformation at night will be especially influenced by the temperature, though also by other factors influencing respiration and growth.

If the magnitude of these diurnal changes is great, it is obvious that farmers should be acquainted with the facts so that, where possible they may adjust their practices to take best advantage of the changes in order to insure a maximum food value of the harvested crop. If diurnal variations are large these may also significantly influence the findings and interpretations of investigations dealing with yield and composition of the vegetative parts of plants.

Many investigations have been carried out with several forage crops to determine the influence of the stage of development on the food value and total yield, that is the progressive changes from day to day or week to week as the plants are developing from young stages to maturity. Although no thorough search of the literature has been made, the writer has seen no report dealing with the diurnal changes occurring in the shoots of forage crops. Miller (6, 7)[3] and Eisele (3) have studied the diurnal changes in carbohydrate and dry matter contents of corn (Miller also worked with sorghum), but they measured changes in leaf blade only and used the leaf-punch method for determining changes per unit area. Since there are diurnal changes in the area of leaf blades which result from changes in water content, differences in actual composition of the leaves based on the use of a punch of constant area may be due either to changes in area or in

[1]Contribution from the Laboratory of Plant Physiology, Cornell University, Ithaca, N. Y. Received for publication November 6, 1943.

[2]Professor of Botany. Funds for carrying out a part of this work were generously supplied by Professor Richard Bradfield of the Department of Agronomy. The four sets of June harvests as well as their analyses were carried out by Palmer J. Waslien while the author was absent on leave. Several other individuals have been of great assistance in harvesting plots and making the detailed analyses.

[3]Figures in parenthesis refer to "Literature Cited", p. 416.

actual composition, or to both. There can be little doubt, however, that the marked differences between afternoon and morning in dry matter and carbohydrate content of the leaf blades reported by Miller (7) and by Eisele (3) are largely real.

In five separate experiments with corn Miller observed gains from morning to afternoon in total dry matter per unit area of leaf blade ranging from 11 to 20% and averaging 17%. In four experiments with sorghum he observed similar gains of from 18 to 25%, averaging 20%. Eisele, in 55 experiments over a 2-year period, observed average daily gains in dry matter per unit area ranging from 5 to 40%. The grand average daily gain for the 55 different days was 15.5%.

Denny (2), by comparing leaves that had been matched in pairs and harvested one of each pair in the afternoon and the other in the morning, measured changes in dry matter and in carbohydrate and nitrogen fractions that took place from afternoon to the next morning. Data from 12 sets of experiments with 6 different species or varieties of beans, including soybeans and lima beans, showed losses overnight of from 6.4 to 17.8% (with a grand average of 12.1% loss) of the total dry matter in the leaf blades.

Reid (8), in following changes in ascorbic acid contents of cowpea plants, determined also the gain in total dry matter of entire plants mostly at 3-hour intervals from morning to evening. In the four sets of data which she presents, total dry matter gains per plant from morning to afternoon range from 17.3 to 23.4% and average 20.4%. In the one set of older plants in which data for tops and roots are presented separately, the tops were 24.8% heavier at 5 p.m. than at 8 a.m.

Krotkov (4) has measured the diurnal changes in carbohydrate contents of wheat leaves. In the five experiments from which data are reported he found the maximum afternoon sugar contents, expressed as percentages of fresh weights, to range between 2 and 4 times the minimum contents in the morning. His data demonstrate marked diurnal changes, but unfortunately they are all expressed as percentages of fresh weight only, and the increased percentage of sugar in the afternoon may have resulted both from an increase in actual sugar and a decrease in water. Furthermore, since he worked with single leaves only, removing all others as the plants grew older, his data may not be typical of normal plants.

PROCEDURE

In order to determine how great the differences between samples cut in the morning and those cut in the afternoon are likely to be, a large number of small plots of alfalfa and several of clover, grass, and corn, were harvested during the summer of 1942. The procedure followed in making the tests was to mark out small plots of uniform areas in natural stands of alfalfa or other crop in the field.[4] For marking out uniform areas wooden frames, as indicated in Fig. 1, were made with sharpened tines or prongs 3 or 4 feet long and spaced a foot apart from center to center. Through the sides of these tines holes were drilled a foot apart through which iron or wooden rods could be thrust, thus marking off plots each a square foot in area. Frames 3 × 3 feet and 4 × 4 feet were used, marking off respectively 9 and 16 areas of 1 square foot each. Larger frames were not feasible

[4]The field of alfalfa was an exceptionally uniform stand of young plants started from seed the spring of the preceding year.

because of difficulties in keeping the tines of larger frames rigid and in line. In fact, for the 4-foot frames it was found helpful to use a sliding guide to keep the tines in line while inserting into the standing crop. In practice, a part of the field of growing alfalfa was chosen where the stand seemed most uniform in areas 3 × 3 feet or 4 × 4 feet, the plants were cut away on one side, the frame laid on this cut side and the tines gently forced into the stand. After the frame was in position rods were thrust through the holes from the side thus marking off the stand into uniform plots of 1 square foot each.

In those experiments in which there were three variables, that is harvests made morning, noon, and afternoon, each of three 3-foot frames allowed for three replications of each treatment, thus making a total of nine replications for each of the morning, noon, and afternoon harvests. The treatments in each of the three frames were arranged in Latin squares (5), the arrangement in each square being chosen at random.

In the other experiments where more than three variables were used, three 3-foot frames and two 4-foot frames were used. This allowed for seven replications of eight different treatments; but since these could not be set up as Latin squares, the arrangement was systematically randomized in seven blocks. Each of the 3-foot frames formed a single block of eight squares (one square in each frame being discarded), and each of the 4-foot frames allowed for two blocks. The randomization of plots was in every case predetermined and plotted on paper before going to the field. Each square foot was harvested by hand with sheep shears or heavy lawn shears, cutting at the level of the cross rods of the frame.

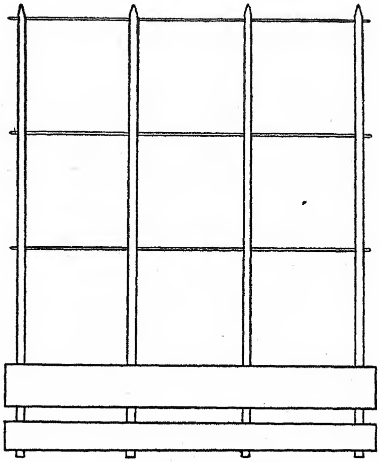


FIG. 1.—Diagram of frame for marking off uniform square foot areas in standing alfalfa.

The material that was to be dried immediately was placed in tared paper bags, the fresh weight taken, and then placed in a large drying oven at about 80°C for 48 hours and finally dried at 85°C. For the material that was to be left in the field over night or for natural drying, the cut tops were spread out on wire fly screen fastened to light wooden frames 14 × 23 inches. These frames with the material on them were left lying on the stubble at the edge of the field. After attaining the desired dryness, the material was transferred from the frames to paper bags and the final oven-dry weight determined as with the material dried directly.

After the oven-dry weights were determined, the material was ground in a Wiley mill to pass a 40-mesh screen. After thorough mixing, the material was

TABLE 1.—*Light in gm. cal/cm² and temperature in °F for the experimental periods.**

	June 10	June 13	June 16	June 21	Aug. 12	Aug. 25
Total light, day of exp.†	655	298	592	337	473	570
Total light, preceding day	715	441	814	779	463	554
Temp. °F night preceding	68°	72°	51°	66°	61°	48°
Temp. °F day of exp	79°	80°	69°	76°	75°	65°
Temp. °F night of exp	—	—	—	—	64°	52°

*The average temperatures between 6 a.m. and 6 p.m. for the day and 6 p.m. to 6 a.m. for the night were roughly calculated from thermograph records.

†This is for the period of the experiment only (5 a.m. to 5 p.m. for the June harvests, and 6 a.m. to 4 p.m. for the August harvests), while that for the preceding day is for the entire day.

redried at 85°C and 6-gram samples from this were extracted in a soxhlet extractor with 80% alcohol. After the usual clearing, the filtrate was hydrolyzed with acid and the total sugar determined by the Munson-Walker method. The residue from the alcohol extraction was allowed to dry in the air, after which it was autoclaved with 100 ml of water, cooled, and the starch hydrolyzed with malt amylase. Following clearing as before, the solution was hydrolyzed with acid and the reducing sugar determined. This was considered a measure of the starch content of the original sample.

From these data the sugar, starch, and total carbohydrate could be expressed either as percentages of dry or fresh weights or as total amount per square foot of harvested area.

The significance of the various data has been tested statistically by the analysis of variance method as outlined by Love (5).

Data on the light and temperature conditions of the periods covered by the experiments reported in this paper are presented in Table 1.

RESULTS

Cuttings of alfalfa were made on June 10, 13, 16, and 21. In each of these four sets of harvests cuttings were made at 5 a.m., 11 a.m., and 5 p.m., eastern standard time, and the material placed in the oven for drying within half an hour after harvesting. The June 10 harvest was

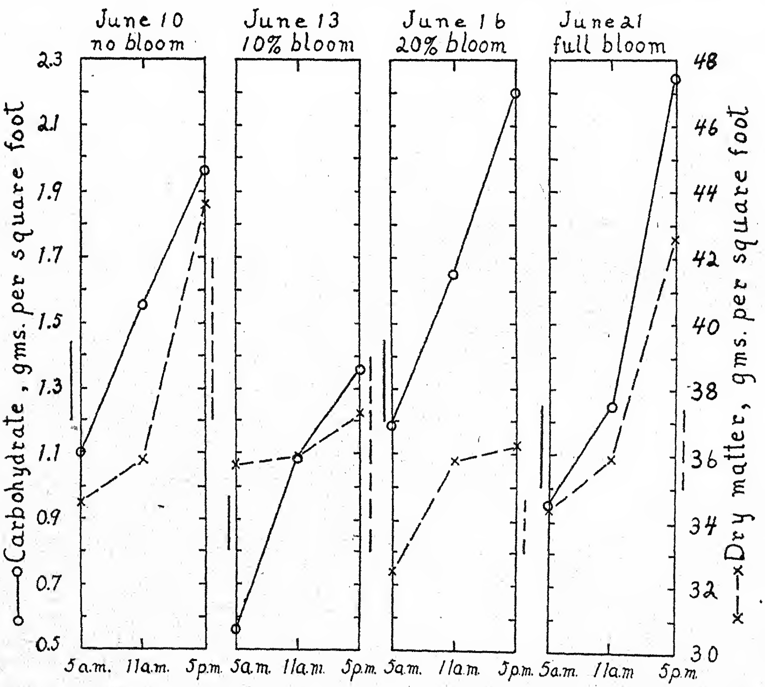


FIG. 2.—Carbohydrate (o—o), starch plus sugar in grams per square foot, refers to the scale at the left. Each point is the average of nine determinations based on the actual dry weights harvested at the time indicated. Total dry matter (x -- x) per square foot refers to the scale at the right. Each point is an average of nine determinations. The vertical solid line at the left and the vertical broken line at the right of each pair of curves indicate the significant differences at the 5% level, odds of 19:1.

taken before any blossoms had appeared which was rather early for normal cutting and the June 21 harvest (full bloom) was a little late. Data showing the total carbohydrate per square foot (average of nine replications for each point) are presented in Fig. 2. The data for carbohydrate contents are indicated by solid lines referring to the scale at the left, while those for total dry matter per square foot are indicated by broken lines referring to the scale at the right. The least significant difference between means at the 5% level (odds of 19:1) is indicated in each case by the vertical solid line at the left for carbohydrate and by the vertical broken line at the right for total dry matter.

It is to be noted in every case that the total carbohydrate and the total dry matter (with the exception of the June 13 harvest) are much higher in the afternoon than in the morning and that the content at noon is intermediate. With the exception of the total dry matter for the cloudy day of June 13, the differences in total carbohydrate and total dry matter per square foot between afternoon and morning harvests are in all cases highly significant. The gains in total dry matter per square foot between morning and noon or between noon and afternoon, although apparent and undoubtedly real, were not in every case clearly significant.[5]

It is to be noted further that the carbohydrate per square foot on the morning of June 13 was much less than that of the previous harvest. When expressed as percentage of dry weight, the carbohydrate content was less than half that of the previous date (1.58 vs. 3.26). This is probably a result of the fact that the two days previous to June 13 were cloudy with slight precipitation (0.07 inch) and with the mean temperature about 15°F warmer than the two days preceding June 10. The high temperature and lack of light would favor depletion of the sugar and starch that had been made the previous days. June 13 was a cloudy day with similar slight precipitation(0.08 inch) and with less than half the light that the plants had received on June 10. This undoubtedly accounts for the smaller gain of both carbohydrate and dry matter on June 13. The percentage gain in carbohydrate was unusually high, however, because of the low level at the start.

The data presented in Fig. 2 are based on material that was cut in the morning, at noon, and in the afternoon of the same day and placed in the drying oven within half an hour after cutting. It is obvious that determinations should also be made of the influences of other methods

[5]It is likely that some will wonder why there was not a steady gain in total yield per square foot as the plants became older from period to period in these June harvests and from the early to the late harvests in August. Both in June and in August different parts of the field were selected for the different experiments so the total yield per unit area, though comparable within each experiment, is not directly comparable between experiments. Furthermore, before the last two harvests of June and the last harvest in August there was marked dying and dropping of the older leaves resulting from crowding. In August there was also considerable lodging of the rank growth and marked loss of the more shaded foliage as well as death accompanied by complete defoliation of many of the smaller plants. For this reason a part of the field showing somewhat less rank growth was selected for the later harvests.

of handling on the composition and yield. Questions that naturally arise are: How much loss is there likely to be if cutting is delayed until the morning following a day of sunshine? How would this loss compare with the loss if the material is cut in the afternoon, left to lie in the field over night, and dried the next morning? How does afternoon cutting compare with morning cutting when the material is not artificially dried but allowed to dry naturally in the field?

In order to obtain data bearing on these questions, randomized plots were set up as before but with seven instead of nine replications for each treatment. The methods of handling the material were as follows:

Treatment 1.—Cut at 6 a.m. (first day) and placed directly in the oven for immediate drying.

Treatment 2.—Cut at 4 p.m. (first day) and placed directly in the oven for immediate drying.

Treatment 3.—Cut at 6 a.m. the next morning (second day) and spread on trays to dry naturally in the field and thereafter exposed to the same drying conditions as those of treatment 4.[6]

Treatment 4.—Cut at 4 p.m. (first day) and spread on trays and left in the field for natural drying over a period of about 2 days.[6]

Treatment 5.—Cut at 6 a.m. the next morning (second day) and placed directly in the oven for immediate drying.

Treatment 6.—Cut at 4 p.m. (first day), left on trays in the field over night, and placed in the oven the next morning at about 7 a.m. the same time as those of treatment 5.

By this procedure it was possible to get data on (a) the gain from morning to afternoon of material immediately dried (treatments 1 and 2); (b) the loss from afternoon to the next morning when cut at these times and immediately dried (treatments 2 and 5); (c) the loss when cut in the afternoon and allowed to lie in the field over night, compared with the loss when allowed to stand over night and cut the next morning, both lots being placed in the oven at the same time the next morning (treatments 6 and 5); and (d) the composition of the material allowed to dry naturally in the field, but one lot cut in the afternoon and the other the next morning (treatments 4 and 3).

Three series of these experiments were carried out with second cuttings of alfalfa, August 12–13, August 19–20, and August 25–26. The material from the August 19–20 harvests was not analyzed for carbohydrates because of the great labor involved in making the many determinations and especially because August 19 was rather cloudy. The dry matter determinations indicated changes very similar to those of August 25–26. The stands of these second cuttings were less uniform than those in the first cuttings of June, but again the data show clear-cut advantages in favor of afternoon cutting. Data showing the total sugar plus starch and total dry matter per square foot of

[6]For the August 12–13 harvest there were very heavy clouds on the August 13 so the cut plants showed no visible wilting. Because of rain the trays with the plants were placed under shelter at 1:30 p.m., August 13. They were placed out on a lawn at 8:00 a.m., August 14, and back under shelter at 5:15 p.m. and again on the lawn at 8:00 a.m., August 15. Appearing sufficiently cured by 1:45 p.m., August 15, they were weighed and placed in the oven for oven-dry weight.

field from the series cut on August 12–13 and August 25–26 are presented in Fig. 3.

Here as in the several June harvests, the gain from morning to afternoon in carbohydrate per square foot (indicated by unbroken lines connecting circles) is very marked and significant for both sets of harvests (treatments 1 and 2, line 1–2). There was also a marked loss of carbohydrate over night (treatments 2 and 5, line 2–5) to a level about the same as that of the morning before. The differences between the levels of treatments 1 and 5, however, are not statistically significant. As was to be expected, there was some loss of carbohydrate from the material cut in the afternoon and allowed to lie in the field over night (treatments 2 and 6, line 2–6), but this loss was much less than that from the material left intact and cut the following morning. This loss from the cut material on standing over night did

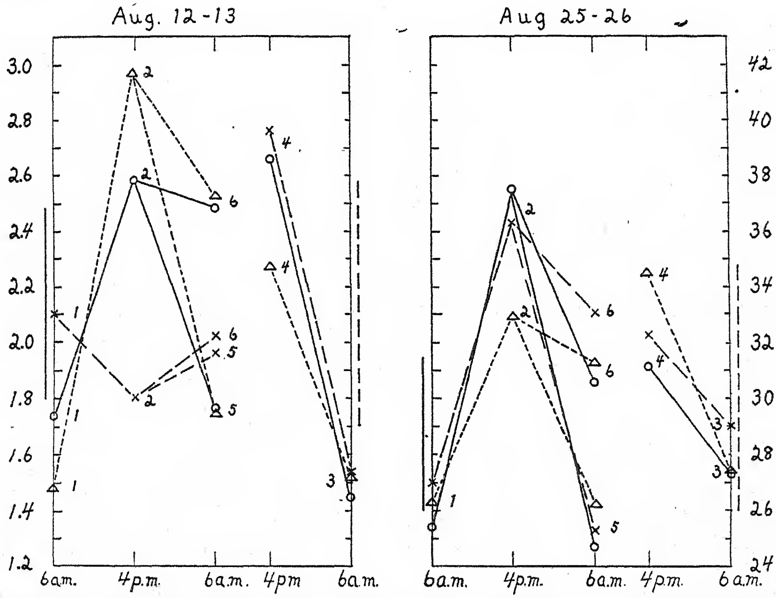


FIG. 3.—Starch and sugar (o—o), in grams per square foot refers to the scale at the left. Each point is the average of seven determinations based on the actual dry weights harvested at the time indicated. Starch and sugar (△ – – △) in grams per square foot refers to the scale at the left. Each point calculated by multiplying the average percentage carbohydrate at the time of harvest (average of seven) by the average of the 21 morning dry weights for the morning figures and the average of 21 afternoon harvests for the afternoon figures. Total dry matter (x – – x) in grams per square foot refers to the scale at the right. Each point is the average of seven determinations. 1, cut at 6 a.m. the first day, dried immediately; 2, cut at 4 p.m. the first day, dried immediately; 3, cut at 6 a.m. the second day, dried naturally in the field; 4, cut at 4 p.m. the first day, dried naturally in the field; 5, cut at 6 a.m. the second morning, dried immediately; 6, cut at 4 p.m. the first day, left lying in the field over night, dried next morning. The least significant difference between any two means at the 5% level for carbohydrate is indicated in each case by the solid vertical line at the left and for total dry matter by the broken vertical line at the right.

not reach the significance level in the August 12–13 harvests but was significant in the August 25–26 harvests.

The material left to dry more slowly in the field over a period of 2 days (treatments 4 and 3) also shows a difference in total carbohydrate per square foot in favor of the afternoon cutting over cutting the following morning. These changes are indicated in the unbroken lines, 4–3 of Fig. 3. This difference was clearly significant in the August 12–13 harvests but did not quite reach the significance level in the August 25–26 series.

The stand of alfalfa available for these second cuttings of August was not as uniform as that in the first cuttings of June. Therefore the dry weights per unit area were more variable. The data for total dry matter per square foot are shown by the crosses connected by broken lines in Fig. 3. For the August 12–13 series there was no significant difference between the morning and afternoon harvests 1, 2, 5, and 6. This was obviously a result of the high variability. The high average for treatment 1 is out of line and probably results from the fact that two of the plots falling in this treatment had the highest original fresh weight of any in the entire lot of 56 plots of this series, in fact higher than all but one of the 168 in the three series. Likewise, two of the plots in treatment 2 had the lowest original weight of all, except one in treatment 5. This probably accounts for the low average for treatment 2. In spite of this high dry weight of treatment 1 and the low dry weight of treatment 2, the total carbohydrate per square foot of the afternoon cutting of treatment 2 was significantly higher than that of the morning cuttings, treatments 1, 5, or 3. There were no such extremes in either treatment 3 or 4 of this series and the difference between total dry weights of afternoon and morning is clearly significant.

In the August 25–26 series of harvests the afternoon cuttings were significantly greater for the afternoon harvest of treatment 2 than for either of the morning harvests of treatment 1 or 5. In this series the difference between treatments 4 and 3 did not reach the significance level. This lack of statistical significance was due to the presence of one plot in the morning harvest (treatment 3) with a total dry weight nearly twice that of the mean. This plot had the highest original weight among all 168 plots in the three series. If this plot is omitted from the mean, the difference between afternoon and morning harvests rises to the level of significance, or even without its omission if both series (August 12–13 and August 25–26) are combined for statistical analysis, the difference becomes significant.

The carbohydrate expressed as a percentage of the total dry matter in every case, in both the August 12–13 and August 25–26 series, was significantly higher in the afternoon cuttings than in the morning cuttings. But since the total dry matter per square foot was rather variable in the August cuttings, the figures for the total carbohydrate per square foot may in some cases be either too high or too low because of the variability in total yield. Since in no case was there a significant difference between total dry matter in any two morning or any two afternoon sets of harvests, while in several cases there were significant differences between afternoon harvests and morning har-

vests, it seemed safer in determining the total carbohydrate per square foot to calculate this on the basis of the average dry weight of the three sets of afternoon harvests (treatments 2, 4, and 6) for the afternoon carbohydrate of each treatment, and the average dry weight of the three morning harvests (treatments 1, 3, and 5) for the morning carbohydrate of each treatment.

The average dry weight for the three sets of afternoon harvests of 21 plots (treatments 2, 4, and 6) for the August 12–13 series is 33.94 grams per square foot and that for the morning harvests (treatments 1, 3, 5) is 30.69 grams per square foot. The corresponding data for the August 25–26 series are 33.89 and 27.07 grams per square foot, respectively. There are no consistent differences between the August 12–13 cuttings and those of August 25–26 so, to eliminate possible individual variations, the data from the two sets were averaged for afternoon and morning harvests; thus, the average of the 42 afternoon harvests is 33.91 grams per square foot and the average of the 42 morning harvests is 28.88 grams per square foot. Statistical treatment indicates the difference between these to be significant, 5.03 ± 1.44, at odds somewhat better than 19:1. The carbohydrate per square foot calculated by multiplying the average percentage carbohydrate for each separate treatment (average of seven plots) by the corresponding average of the 42 afternoon or 42 morning dry weight determinations are indicated in Fig. 3 by the triangles connected by dotted lines. These probably are truer indications of the actual amounts of carbohydrate per square foot as influenced by the different methods of handling than are the other curves.

A summary of other data from the same experiments is presented in Table 2. This summary makes comparisons between what might be considered as 10 separate sets of alfalfa harvests (12 sets if partial duplicates are included). In every case the percentage gain for the afternoon is expressed as a percentage of the morning figure, whether the morning preceded or followed the afternoon cutting. The negative figures for total dry matter in lines *e* and *f* are undoubtedly a result of variability of these plots, as are probably also the excessively high figures in lines *g*, *i*, and *j*. The grand average at the bottom of the table, however, probably gives a fairly clear indication of what might be expected when comparing afternoon cuttings with morning cuttings, for each of these grand averages represents an average of the harvests from 78 separate square-foot plots harvested on 8 different days. In fact when each of the 24 sets of comparisons of the dry matter and carbohydrate per square foot between morning and afternoon harvests was examined statistically, there were only five instances in which the differences did not reach the significance level. When carbohydrate was expressed as percentage of dry weight, there was, without exception, a significant advantage in favor of afternoon cutting.

This grand average indicates a gain of 83% total carbohydrate per square foot or per acre in the afternoon cuttings over the morning cuttings. In like manner there is indicated an average gain of 19% in total dry matter per unit area when cut in the afternoon over that cut in the morning. (If the more variable harvests of August 12–13 are omitted, the gains in carbohydrate average 90% and total dry matter

TABLE 2.—*Summary showing effects of afternoon vs. morning cutting on the carbohydrate and dry matter in alfalfa.**

Data and procedure	Carbohydrate, % dry weight		Dry weight, % fresh weight		Gain when cut in afternoon over that cut in morning				Ratio, gain of total dry matter to gain total carbohydrate
					Carbohydrate		Total dry matter		
	Morning cut	Afternoon cut	Morning cut	Afternoon cut	Pounds per acre†	%	Pounds per acre†	%	
A, June 10, dried immediately	3.26	4.48	20.6	24.4	83± 4.4	79	875±129	26	10.5
B, June 13, dried immediately	1.58	3.64	18.6	24.1	76± 5.5	140	154±183	5	2.0
C, June 16, dried immediately	3.66	6.66	19.9	24.4	97± 8.2	85	375± 53	12	3.9
D, June 21, dried immediately	2.76	5.27	17.8	24.6	125± 8.2	138	797± 78	24	6.4
E, Aug. 12, dried immediately (treatments 2 and 1)	5.15	8.75	19.3	25.0	82±22.2	49	−164±202	−5	−2.0
F, Aug. 12, aft.; Aug. 13 morn., dried immed. (treatments 2, 5)	6.03	(8.75)	20.2	(25.0)	108±22.2	77	−154±202	−5	−1.4
G, Aug. 12, aft.; Aug. 13, morn., dried naturally (treatments 4, 3)	5.25	6.71	18.1	24.0	117±22.2	84	1184±202	49	10.2
H, Aug. 12, aft., in field over night; Aug. 13, morn., both dried in morning (treatments 6, 5)	(6.03)‡	7.44	(20.2)	25.5	98±22.2	70	63±202	2	1.0
I, Aug. 25, dried immed. (treatments 2, 1)	4.94	6.18	22.4	28.0	116±12.8	91	900±180	35	7.8
J, Aug. 25, aft.; Aug. 26, morn., dried immed. (treatments 2, 5)	4.92	(6.18)	19.6	(28.0)	123±12.8	101	1060±180	44	8.6
K, Aug. 25, aft.; Aug. 26, morn., dried naturally (treatments 4, 3)	5.33	6.60	20.8	25.6	58±12.8	39	302±180	11	5.3
L, Aug. 25, aft., in field over night; Aug. 26, morn., both dried in morn. (treatments 6, 5)	(4.92)	5.68	(19.6)	25.5	57±12.8	47	740±180	30	13.1
Grand averages	4.31	6.14	19.7	25.1	95	83.3	512	19.0	5.4

*Each figure an average of nine samples for the June cuttings and seven for those of August; each sample analyzed separately.
†Probable error of the difference between two means.
‡Figures in parenthesis not included in grand average because a replication of an identical figure.

23%.) This amount of gain in total dry matter is much greater than was expected but is based on such a large number of individual plots replicated in several independent experiments that the figure seems fairly reliable. In fact, when divided into subtreatments making comparisons of different methods of drying and thus involving only seven replications of morning and afternoon harvests for each subtreatment, there was in most cases an advantage in favor of afternoon cutting that was statistically significant. The grand average includes some figures for dry matter per unit area that are obviously excessively high, but it contains also figures that are obviously too low and are in fact negative. It also includes figures for periods that were so cloudy that any marked gain in total dry matter was not to be expected.

Disregarding possible effects of different methods of drying the samples, comparison was made between dry weight yields of morning and afternoon harvests by averaging the three morning harvests for treatments 1, 3, and 5 for each of the seven sets of the August 25–26 series and likewise the three afternoon harvests for treatments 2, 4, and 6. This gave seven replications, each one consisting of the average of either three morning harvests or three afternoon harvests. These data show an average yield of dry matter in grams per square foot of 26.79 for the 21 morning harvests and 33.89 for the afternoon harvests, a difference in favor of the afternoon of 7.1 grams, or 26.5%. Statistical analysis of the data indicates a difference of 5.5 grams to be significant at the 5% level (odds of 19:1).

A similar comparison was made between afternoon and morning harvests for the three series of August 12–13, August 19–20, and August 25–26, thus comparing harvests from a total of 126 plots arranged as 21 averages each of three afternoon and three morning harvests. The mean of the 63 afternoon harvests was 32.64 grams per square foot and that for the 63 morning harvests was 28.42 grams per square foot, with a difference of 4.22 grams per square foot. Statistical analysis indicates a difference of 3.65 grams to be significant at the 5% level. The average of afternoon yields was 14.9% greater than the average morning yields in spite of the fact that one third of the afternoon harvests was made on a partly cloudy day with a total of 472 gm.cal/cm^2 of incident radiation, or 69% of the light intensity of a clear day of the previous week, and another third on a day with total light intensity of 511 cal/cm^2, or 75%. The light for the clearest day (August 25) was 634 cal/cm^2, or 93% of that of a clear day.

Since the gross gain of 19% or 500 pounds of dry matter per acre on a single clear day seemed excessively high, a search has been made for possible supporting data. As already stated, average daily gains of dry matter in foliage alone commonly equal the above percentage figure and on many days greatly exceed that figure. There seems to be little or no evidence dealing directly with daily gross gains of the entire vegetative shoot. Data helpful in calculating such gains are presented by Thomas and Hill (9). They measured the apparent photosynthesis of alfalfa enclosed in glass chambers. Their highest apparent photosynthesis, net gain for a single daylight period as measured by CO_2 absorption, is reported in their Table 4 and indicates a gain of 425 pounds of dry matter per acre per day. The average daily gross gain

of dry matter for the entire period of this experiment, July 15 to August 7, was 345 pounds per acre per day. The net gain of the tops by the end of the experiment was of course much less than this, being reduced by night respiration and by translocation to the roots. Their maximum as well as their daily average figures were both lower than the 500 pounds indicated by the data reported here. A lower day by day figure, however, would be expected under their conditions because their curves indicate continuous clear weather day after day with only occasional clouds, whereas one would expect maximum gross gains on occasional clear days that follow cloudy ones as was the condition in the writer's experiments. Furthermore, in their experiments the CO_2 from root and soil respiration would tend to lower their measured figure for apparent assimilation during the day.

A matter of considerable interest is indicated in the last column in Table 2. In nearly every case the gain in total dry matter per square foot for the afternoon cutting greatly exceeded the gain in total carbohydrate as measured by starch and sugar, the average gain in total dry matter being about 5 times that of carbohydrate. This would indicate a conversion of a large part of the photosynthate to some compounds not recoverable as sugar and starch. There is probably a slight gain in mineral content during the day, but this would account for only a very small part of the gain in total solids.

As indicated in the columns giving the percentages of dry weight (Table 2), the water contents of the morning cuttings were invariably higher than those of the afternoon cuttings. Calculations show that, on the average, the actual water per square foot of the cuttings made in the mornings was 17.7 grams (1,684 pounds per acre), or 16.3%, greater than in the afternoon cuttings. This, however, is a greater difference than the actual water in the plants because there was considerable dew and water of guttation on the surface of most of the plants harvested in the morning. For this reason it seemed of little value to give the actual water contents or the carbohydrate expressed as percentages of fresh weights.

Because of its higher sugar content one would expect material that is cut in the afternoon to dry somewhat more slowly than that cut in the morning (1). Although the morning cuttings initially had a much higher water content than those cut in the afternoon, by midafternoon (3:40 p.m., August 26) those cut in the morning and exposed on trays contained on the average 52.3% water while those cut on the previous afternoon contained 54.8%. The morning samples had lost 58.2% of their original fresh weight, while those cut on the previous afternoon had lost 47.4%. The actual difference in rate of water loss between afternoon and morning samples was not as great as these figures indicate for the fresh weight of the afternoon sample was that taken at the time of harvest. These samples lay on trays in the field and were dripping with dew at the time the morning samples were harvested and therefore must have had a higher fresh weight than when cut the previous afternoon. They were not weighed at this time because the trays as well as the plants were heavy with dew.

When field drying was completed in treatments 3 and 4, the stems and leaves were separated to determine the effect of time of cutting

on the distribution of water as well as carbohydrates between stems and leaves. In the morning harvests (treatment 3) the carbohydrate content of the stems was 4.33% of the dry weight and that of the leaves 6.77%. In the afternoon harvests (treatment 4) the stems contained 5.63 and the leaves 7.87% carbohydrate. When placed in the oven at the conclusion of the natural drying in the field, the material cut in the morning (treatment 3) contained 29.9% water in the stems and 9.5% in the leaves, while that cut in the afternoon (treatment 4) contained 32.8% moisture in the stems and 5.8% in the leaves. Thus, in this particular series, which is the only one in which stems and leaves were separated after field drying, there was somewhat more water in the stems and less in the leaves of the material cut in the afternoon when compared with that cut in the morning. The average water contents of the entire plants, stems and leaves, was slightly higher in the material cut in the afternoon than that cut in in the morning, 22.24 and 22.09%, respectively. Thus, although the rate of drying is somewhat slower when cut in the afternoon, this is a result of the higher food content at that time, and the higher food value would probably much more than offset any disadvantages of slower drying.

DISCUSSION

The data here presented demonstrate that the carbohydrates (starch and sugar) and total dry matter contents of alfalfa tops are much higher in afternoon cuttings than in cuttings made in the early morning. They demonstrate that this advantage for afternoon cuttings over morning cuttings obtains independently of whether the morning cuttings are made the morning before the afternoon cuttings or the next morning following the afternoon cuttings. They also clearly indicate that this advantage in favor of afternoon cutting is largely independent of the method of drying, that is, whether dried immediately in an oven or naturally in the field.

There is evidence that the greater part of the gain in total dry matter during the day is a gain in easily digestible foods. Therefore, a gain of 10% in total dry matter will probably mean a much greater percentage gain in food value because much of the original dry matter has a low digestibility. The amount of difference between morning and afternoon cutting will probably vary considerably with the stage of development of the plants and the weather conditions during the day when the cuttings are made, as well as the conditions one to several days previous to the cutting. Preliminary data as well as theoretical considerations indicate that, during periods when rapid vegetative growth is taking place, the difference between morning and afternoon cuttings will be greater than when the plants are more nearly mature. Then, too, if the weather previous to the day of cutting has been cloudy and wet, the initial carbohydrate and dry matter are likely to be low, and the gain during a clear day following such weather is apt to be greater than on a clear day following several other clear days. The loss over night following such a single clear day can be expected to be much greater than the loss over night following a succession of clear days, because under the conditions of the single clear day carbo-

hydrate is likely to be the chief limiting factor and will thus be depleted more rapidly. If the night is warm, the depletion of carbohydrate would obviously be greater than if it is cold, since the temperature would influence the rate of utilization in respiration and growth as well as the rate of conversion to other constituents and the rate of translocation to the roots.

The weather conditions prevailing over the greater part of the period during which the experiments here reported were carried out were such as to favor great differences between carbohydrate and dry matter contents between afternoon and morning. It is probable that smaller differences would be found during prolonged periods of clear weather and during periods of drouth. It is often claimed that, although large yields of what look like high quality hay may be produced during wet seasons, this hay sometimes does not "feed out well" even when the weather during the harvesting period may be favorable for curing. The findings here reported would suggest that the low food value of hay produced under such conditions is partly a result of the low carbohydrate associated with low light intensities and high water supply. During such seasons early morning cuttings would tend to accentuate the carbohydrate deficiency.

Both from theoretical considerations and experimental data thus far obtained it appears that the nutritive value of forage crops is likely to be much higher when cut in mid- or late afternoon than when cut early in the morning. Recent recommendations from some sources that hay be cut early in the morning while still wet with dew and from others that it be cut immediately after the dew has evaporated would probably result in hay with a minimum or low food value. Unless other factors complicate matters, it seems that the practice followed by some farmers of cutting forage crops in the middle or late afternoon and letting the material lie in the field over night to dry through the following day or two will result in material with a higher food content than when cutting is done early in the morning. If the hay can be artificially dried or partly dried by forced ventilation, as described for example by Weaver and Wylie (10), it may be more feasible to take advantage of afternoon cutting.

It is obvious also that the quality of ensilage made from corn, grass, or legumes will be partly influenced by the time of day at which the material is cut before placing in the silo. Afternoon cutting would obviously favor a lower total as well as lower percentage water content and a higher total as well as higher percentage carbohydrate content of the material.

Experiments similar to those with alfalfa have already been carried out with grass, corn, clover, and soybeans. Though not yet entirely completed, analyses of these materials clearly indicate differences in carbohydrate similar to those found in alfalfa. These are to be reported at a later date.

The data here presented indicate that the time of day at which forage crops are cut is likely to have an important effect on the food value of the crop, an effect greater than has been commonly recognized. It is obvious that many more experiments should be carried out, testing under more varied conditions and with more kinds of

crops. It is also obvious that more complete analyses should be made, including also feeding tests with animals. The author would prefer to have delayed publication of these results until he could have completed more of these tests, but in view of the possible importance in application to practice it seemed best to publish without further delay.

SUMMARY

Many plots each a square foot in area were marked off by frames inserted in a field of alfalfa. Similar areas were harvested at different times over a 12- or 24-hour period. In several experiments cuttings were made at 5 a.m., 11 a.m., and 5 p.m. eastern standard time of the same day. In others they were made at 6 a.m. and 4 p.m. of the first day and 6 a.m. the following morning. In most cases the material was placed immediately in the oven for drying. In other cases the cut plants were left to dry naturally in the field over a period of 2 days.

Analyses for sugar and starch demonstrate that the alfalfa samples cut early in the morning had the lowest carbohydrate content when expressed either as percentage dry weight or as total carbohydrate per unit area of field, and that carbohydrate increased from morning to noon and from noon to afternoon.

The total dry matter per unit area of field also increased from morning to afternoon.

The carbohydrate and dry matter in the afternoon were greater than in the morning independently of whether the material was dried immediately in an oven or was left in the field to dry naturally. They were greater also independently of whether the morning harvest preceded or followed the afternoon harvest.

When cut in the afternoon and allowed to lie in the field over night and then placed in an oven at the same time with similar plots left standing intact over night and cut the following morning, the plots cut in the afternoon were found to contain more carbohydrate and more dry matter.

Grand averages of all 10 sets, consisting of seven to nine replications for each set, indicate a carbohydrate content 83% higher and a dry matter yield 19% higher in afternoon cuttings than in the morning cuttings.

Examination of the data by the method of analysis of variance indicates that the differences between afternoon and morning cuttings in amounts of carbohydrate as well as dry matter per square foot of area are clearly significant in most cases.

In most cases the differences in total dry matter per square foot were several times the difference in sugar and starch. The grand average of these ratios indicate that starch and sugar account for only about one fifth the difference in dry weight.

These findings suggest that, where other considerations do not interfere, there would be a distinct advantage in cutting alfalfa and other forage crops in the afternoon rather than in the morning. The data also indicate that the composition of leafy materials, especially when expressed on a dry weight basis, is likely to be significantly influenced by the time of day at which the materials are cut as well as by the weather conditions immediately preceding the cutting.

LITERATURE CITED

1. BOON-LONG, T. S. Transpiration as influenced by osmotic concentration and cell permeability. Amer. Jour. Bot., 28:333–343. 1941.
2. DENNY, F. E. Changes in leaves during the night. Contr. Boyce Thompson Inst., 4:65–83. 1932.
3. EISELE, H. F. Influence of environmental factors on the growth of the corn plant under field conditions. Iowa Agr. Exp. Sta. Res. Bul. 229:254–287. 1938.
4. KROTKOV, G. Diurnal changes in the carbohydrates of wheat leaves. Can. Jour. Res., 21:26–40. 1943.
5. LOVE, H. H. Application of Statistical Methods to Agricultural Research. Changsha: Commercial Press. 1938.
6. MILLER, E. C. Daily variation of water and dry matter in the leaves of corn and sorghums. Jour. Agr. Res., 10:11–45. 1917.
7. ————. Daily variation in the carbohydrates of corn and the sorghums. Jour. Agr. Res., 27:785–808. 1924.
8. REID, MARY E. Variations in ascorbic acid and dry matter content of cowpea plants at different times of day. Bul. Torrey Bot. Club, 69:522–527. 1942.
9. THOMAS, M. D., and HILL, G. R. Relation of sulphur dioxide in the atmosphere to photosynthesis and respiration of alfalfa. Plant Physiol., 12:309–383. 1937.
10. WEAVER, J. W., and WYLIE, C. E. Drying hay in the barn and testing its feeding value. Tenn. Agr. Exp. Sta. Bul. 170. 1939.

INHERITANCE OF DWARFNESS IN COMMON WHEAT[1]

W. K. Pao, C. H. Li, C. W. Chen, and H. W. Li[2]

THE studies of the inheritance of dwarfness in common wheat were summarized by Kihara (1)[3] in 1938. Since the data obtained by different workers varied greatly from one another, the interpretations were also different. The results were explained on the basis of the following hypotheses: (a) There are two dominant complementary factors for dwarfness D_1 and D_2; (b) a factor I or N, when in a dominant condition, inhibits the action of D_1 and D_2; and (c) a second factor, E, in a dominant condition inhibits the action of I.

In the fall of 1939, the writers obtained dwarf wheat plants among F_2 segregates of two varietal crosses. In subsequent years the frequencies of dwarf plants were studied in some other crosses and backcrosses. These results could not be accounted for satisfactorily by the previous hypotheses. The data obtained have been summarized and a genetic interpretation has been suggested.

MATERIAL AND METHODS

The inheritance studies of dwarfness were obtained largely from the material in the breeding plots. In order to study the mode of segregation in F_3, the progenies of random selections of F_2 plants were grown.

From crosses of the F_1 of one of the varietal crosses with a pure line, 2905, dwarf plants were obtained. This led to the hypothesis that the inhibitor I was not present in 2905, and therefore 2905 was used frequently in three-way crosses and crosses with dwarf plants. The line 2905 has been very helpful in the final interpretation of the results as it was found to be a multiple recessive as far as the factors for dwarfness were concerned.

DESCRIPTION OF THE DWARF PLANTS

The dwarf plant is not discernible at the very young stage. About 20 days after sowing, it begins to manifest itself by developing darker green and stiffer leaves as compared with the normal sibs. In about 40 days, it can be differentiated clearly by its characteristic tuft of dark green and stiff leaves and also by its profused condition of tillering. This tuft condition is due to nothing more than the closeness of the distance between the secondary stems. At maturity the dwarf plants are about 1 foot in height. Their leaves continue to be darker green with shorter and narrower leaf blades than their normal sibs. The condition of tillering in the dwarfs is so profused that the number of tillers usually amounts to 50 or more (Fig. 1).

Date of heading in dwarf plants is about 2 weeks later than their normal sibs, and many of the tillers fail to come out of the boot. Consequently, maturity is delayed, and many heads are left empty as a result of the rising temperature which is detrimental to the normal growth of wheat plants. Hence, only very few seeds are obtainable from the dwarfs in spite of a large number of tillers.

---

[1]Contribution from the Rice and Wheat Improvement Institute of the Szechuan Provincial Agricultural Improvement Institute, Chengtu, Szechuan, China. Journal Series No. 5. Received for publication December 8, 1943.

[2]Technician of the Szechuan Agricultural Extension Station of the Ministry of Agriculture and Forestry of China, Senior Agronomist of Kausu Provincial Agricultural Improvement Institute, Associate Agronomist, and Director of the Rice and Wheat Improvement Institute, respectively.

[3]Figures in parenthesis refers to "Literature Cited", p. 428.

EXPERIMENTAL RESULTS AND INTERPRETATION

CROSSES BETWEEN QUALITY AND P165

Quality originated from America and P165 from India. The F_1 of the cross of these two varieties was normal and F_2 segregated into 15,881 normals and 3,341 dwarfs. The ratio of normals and dwarfs is approximately 4.8:1, which seems to be very close to 13:3. But, owing to the large population in F_2 which is 19,222, the ratio obtained shows a highly significant deviation from 13:3. It was first supposed that this deviation was probably a result of low germinability of seeds containing the dwarf genotype. By comparing the percentage of germination of those lines that do not show any segregation and those with segregation, however, there seems to be no difference between them. Furthermore, intra comparison of different lines reveals that they deviate as high as 10% or more in germination yet the ratio remains unchanged. It seemed probable, therefore, that there were more than two factors involved. The factors first postulated were as follows: (a) Two complementary factors, D_1 and D_2 for dwarfness; (b) a duplicate factor, D′; and (c) an inhibitor, I.

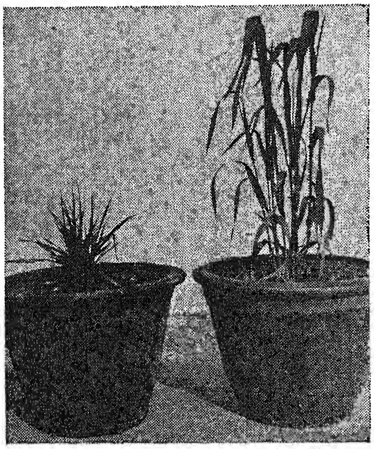


FIG. 1.—*Left*, dwarf; and *right*, and normal plants.

Theoretically, an interaction of these four factors would give an F_2 segregation ratio of 211 normals to 45 dwarfs. This is very close to the 4.8:1 ratio actually obtained in F_2. The results of the F_2 segregations of the crosses are presented in Table 1.

There were 10 different F_2 lines grown in 1940 that segregated for normal and dwarf plants. A P value of .05 and n of 1 would be obtained from a X^2 value of 3.841. All F_2 values gave a P value higher than .05, indicating that no ratios deviated widely from the calculated ratio of 211:45. The calculated P value of the 10 F_2 crosses grown in 1940 was .782 and for the two F_2 crosses grown in 1942 was .747 indicating an excellent agreement between the observed and calculated ratios when the results from different F_2 lines were combined.

To further test the hypothesis, F_3 progenies were grown from plants that were normal in F_2 and the F_3 lines were placed in two groups, those that again gave both normal and dwarfs classified in Table 2 as segregated and F_3 lines with only normal plants classified as non-segregated. On the basis of the hypothesis 90 out of 211 normal plants in F_2 would give segregating progeny in F_3. Several of the F_3 lines gave higher X^2 values than 3.841, showing a significant deviation from the theoretical 90:121. The total for the 10 F_3 lines was 180 that segregated : 353 giving only normal plants. Compared with calculated the

TABLE 1.—F_2 results of the crosses between Quality and P165.

Line No.	Germination, %	Observed		Calculated (211:45)		x^2
		Normal	Dwarf	Normal	Dwarf	
			1940			
2A	64.8	1,572	321	1,560.25	332.75	0.503
2B	67.4	817	164	808.56	172.44	0.502
2C	56.1	1,030	197	1,011.32	215.68	1.963
2D	58.1	1,517	354	1,542.11	328.89	2.326
2E	51.3	1,317	272	1,309.68	279.32	0.233
2F	58.8	2,021	438	2,026.75	432.25	0.092
2G	66.1	2,051	440	2,053.13	437.87	0.012
2H	61.7	2,003	422	1,998.73	426.27	0.052
2I	60.1	1,630	337	1,621.24	345.76	0.269
2J	67.8	1,923	396	1,911.36	407.64	0.403
Total...	61.2 (av.)	15,881	3,341	15,843.13	3,378.87	6.403
			1942			
6–18	35.9	230	47	228.31	48.69	0.072
6–19	44.7	87	22	89.84	19.16	0.511
Total...	40.3 (av.)	317	69	318.15	67.85	0.583

P value was less than .01, indicating a significant deviation. As some F_3 lines had small progenies this may account for a larger proportion of nonsegregating lines than the theoretical expectation.

When F_1 was backcrossed to the pure line 2905, which is supposed to be multiple recessive, theoretically, a 13:3 ratio would be obtained ($F_1 = D_1d_1\,D_2d_2\,D'_1\,d'_1\,Ii$). Thirty-one normals and six dwarfs were obtained. This is indeed a close fit as indicated by a P value of .694.

From the results obtained in F_2, F_3, and backcross, it seems reasonable to conclude that segregation of dwarfs in this cross be-

TABLE 2.—F_3 results of the crosses between Quality and P165.

Line No.	Total number of sub-lines	Observed		Calculated (90:121)		x^2
		Segregated	Nonsegregated	Segregated	Nonsegregated	
2A	162	53	109	69.10	92.90	6.541
2B	12	6	6	5.12	6.88	0.264
2C	12	7	5	5.12	6.88	1.204
2D	30	9	21	12.80	17.20	1.968
2E	46	12	34	19.62	26.38	5.160
2F	105	31	74	44.79	60.21	7.404
2G	40	12	28	17.06	22.94	2.617
2H	69	28	41	29.43	39.57	0.121
2I	25	9	16	10.66	14.34	0.450
2J	32	13	19	13.65	18.35	0.054
Total.....	533	180	353	227.35	305.65	25.783

tween Quality and P165 is due to the interaction of four factors. The origin of these factors in the two parents will be discussed later.

CROSSES BETWEEN P165 AND 25V112

25V112 is an accession number for an Italian variety in Professor Percival's collection. When it was crossed with P165, F_1 was normal. In the F_2, ratios varied with different 25V112 parents used, namely, no segregation, about normal to dwarf, 8.6:1 and about 5.2:1. This diversity of segregation ratios can be attributed to the impurity of the 25V112 used. It has been found that the plants of variety 25V112 have different genotypes owing to frequent natural hybridization. This condition is apparent in the field of 25V112, by the admixture of types of heads, glume color, beardness, height of plant, and winter or spring habit of growth, found in 25V112. For the sake of convenience, the 25V112 parent used in making crosses that gave an 8.6:1 ratio is designated as 25V112-1 and the other parent that when crossed gave a 5.2:1 ratio as 25V112-2.

The results obtained in crossing P165 × 25V112-1, as shown in Table 3, can be explained by the interaction of three complementary factors, D_1, D_2, and D_3, and an inhibitor I. This will give a theoretical ratio of 229:27 which is about 8.5:1, a very close fit to the observed 8.6:1 as the P value equals .694 for these lines.

TABLE 3.—*F_2 results of the crosses P165 × 25V112-1 in 1940.*

Line No.	Germination, %	Observed		Calculated (229:27)		χ^2
		Normal	Dwarf	Normal	Dwarf	
5A	71.4	211	19	205.74	24.26	1.275
5E	70.4	820	101	823.86	97.14	0.171
5G	76.9	1,160	136	1,159.31	136.69	0.004
Total...	72.9 (av.)	2,191	256	2,188.91	258.09	1.450

Assumption can be made for the other cross P165 × 25V112, as shown in Table 4, by assuming an interaction of three complementary factors, D_1, D_2, and D_3, an inhibitor I, and two duplicate factors, D_1' and D_3'. This would give a theoretical ratio of 3421:675, which

TABLE 4.—*F_2 results of the crosses P165 × 25V112-2.*

Line No.	Cross	Year	Germination, %	Observed		Calculated (3421:675)		χ^2
				Normal	Dwarf	Normal	Dwarf	
5F	P165×25V112-2	1940	62.9	289	57	288.98	57.02	0.000
5H	P165×25V112-2	1940	72.0	394	73	390.04	76.96	0.244
6-4	25V112-2×P165	1942	29.4	252	48	250.56	49.44	0.050
Total				935	178	929.58	183.42	0.294

is about 5.1:1, a very close fit to the observed 5.2:1 as the P value is .960 for the three lines.

When F_1 of this cross is backcrossed to the multiple recessive 2905, 62 plants and 15 dwarfs were obtained. The calculated ratio was 66.17:10.83. This is a close fit as shown by a P value of 0.179.

Up to the present, we have assumed the genotypes for the F_1 of three different crosses to be as follows:

Crosses	F_1
P165 × 25V112-1	$D_1d_1\ D_2d_2\ D_3d_3\ I_i$
P165 × 25V112-2	$D_1d_1\ D_2d_2\ D_3d_3\ D'_1d_1'\ D'_3d'_3\ I_i$
Quality × P165	$D_1d_1\ D_2d_2\ D_3D_3\ D'_1d'_1\ I_i$

D_3 must be present before dwarfs can appear. Therefore, it is assumed that D_3 must be present in both P165 and Quality. D'_1 comes from Quality and D'_3 from 25V112-2, according to the results obtained so far. It remains to account for the parental origin of D_1, D_2, and I. This will be discussed later.

OTHER CROSSES

A series of other crosses were made with the following wheats: (a) 7L1 and 6L1, *Triticum sphaerococcum* from Prof. Percival's collection; (b) Mo's 101, a selection after hybridization; (c) Purplestraw and Marshall's No. 3, American varieties; (d) Ardito, an Italian

TABLE 5.—*F_2 segregation in other crosses.*

Line No.	Cross	Year	Germination, %	Observed Normal	Observed Dwarf	Calculated Normal	Calculated Dwarf	χ^2
						(3,421:675)*		
3C	Quality × Mo's 101	1940	—	1,741	334	1,733.05	341.95	0.221
2	7L1 × Noogaar	1941	—	223	36	216.32	42.68	1.252
5	7L1 × Fawn	1941	—	423	59	402.57	79.43	6.292
11	6L1 × Fawn	1941	—	462	89	460.20	90.80	0.043
14	7L1 × Florence	1941	—	520	98	516.16	101.84	0.174
						(13:3)		
26	7L1 × Majestic	1941	—	430	117	444.44	102.56	2.502
36	7L1 × Marshall's No. 3	1941	—	470	109	470.44	108.56	0.002
1-2	Onas × Quality	1942	36.8	270	62	269.75	62.25	0.001
1-3	Fawn × Quality	1942	38.7	100	27	103.19	23.81	0.526
1-5	Purplestraw × Quality	1942	44.7	590	134	588.25	135.75	0.028
1-7	Rajah × Quality	1942	52.5	261	69	268.12	61.88	1.008
1-9	Majestic × Quality	1942	36.4	401	85	394.88	91.12	0.506
1-10	Omaral × Quality	1942	43.4	535	140	548.44	126.56	1.756
3-2	Onas × Ardito	1942	18.3	48	12	48.75	11.25	0.066

*With an n of 1 and χ^2 of 3.801 P = .05.

variety; and Noogaar, Fawn, Florence, Majestic, Onas, Rajah, and Omaral, Australian varieties.

It can be seen from Table 5 that there are two types of segregation in these crosses. The first approaches a 3421:675 ratio and F_1's are assumed to have a genetic constitution of D_1d_1 D_2d_2 D_3d_3 D'_1 d'_1 $D'_3d'_3$ Ii. For the second type, a 13:3 ratio is calculated with a segregation for Dd Ii and the homozygous condition of other factors essential in producing dwarfs. None of the observed deviate significantly from the calculated, except line No. 5 for which P equals .013.

F_3 progeny from normal plants of F_2 of the crosses that give 3,421:675 were grown. Theoretically, one would expect $2(3\times3\times3\times4\times4+2\times3\times3\times3\times4+3\times3\times3)$ or 1,350 out of 3,421 that will segregate again for dwarfs; the remainder, 2,071, will not. This expectation is realized as presented in Table 6. P value for these five lines is .066.

Should the above assumption be true, one would obtain lines in F_3 that will give segregation ratios as 3,421:675, 899:135, 799:225, 211:45, 229:27, 49:15, 55:9, 13:3, and 3:1. These nine types of segregation ratios will occur in a ratio of 64:128:32:288:64:112:256:308:98.

TABLE 6.—*F_3 lines of different crosses.*

Line No.	Cross	Observed		Calculated (1,350:2,071)*		χ^2
		Segregated	Nonsegregated	Segregated	Nonsegregated	
3C	Quality × Mo's 101	11	33	17.36	26.64	3.897
2	7L1 × Noogaar	1	1	0.79	1.21	0.090
5	7L1 × Fawn	51	66	46.17	70.83	0.834
11	6L1 × Fawn	49	56	41.44	63.56	2.278
14	7L1 × Florence	55	60	45.38	69.62	3.368
Total		167	216	151.14	231.86	10.467

*With an n of 1 and χ^2 of 3.841 P = .05.
With an n of 5 and χ^2 of 10.467 P = .066.

It is unfortunate that the total number of F_3 lines is only 167, and the number of plants in each line is also not great enough to render a correct assignment of the exact ratio, so it is not possible to compare the observed with the calculated. Instead, some of the lines containing sufficient plants to ascertain a definite assignment of the ratio to which they might belong are chosen to show the existence of all these nine types mentioned above. These results are summarized in Table 7.

There are several other crosses that do not give segregation in F_2. (a) 2905 × Quality; (b) 2905 × P 165; (c) 2905 × 25V112; (d) 25V112 × Quality; (e) Rajah × Fawn; (f) Onas × Majestic; (g) Onas × Fawn.

From the results obtained so far, the genotypes of different parents can be ascertained, with special reference to D_1, D_2, and I. When Quality is crossed with Onas, Omaral, Rajah, Fawn, and Purplestraw, F_2's give 13:3 ratios, indicating segregation for the Dd and Ii factor pairs. Supposing the genotype of Quality is D_1D_1 d_2d_2 D_3D_3

$D'_1D'_1$ $d'_3d'_3$ ii, then the genotypes for Onas, etc., would be D_1D_1 or $D'_1D'_1$, D_2D_2 D_3D_3 and II. This assumption is rather consistent with the results obtained. It explains the reason why crosses of the varieties Onas with Majestic, Onas with Fawn, and Fawn with Rajah will give no segregation in F_2.

Accordingly, since the genotype of the F_1 of the cross Quality and P165 is D_1d_1 D_2d_2 D_3D_3 $D'_1d'_1$ $d'_3d'_3$ I_i, the genotype of P165 would be d_1d_1 D_2D_2 D_3D_3 $d'_1d'_1$ $d'_3d'_3$ II. Then, 25V112-1 would be D_1D_1 d_2d_2 d_3d_3 $d'_1d'_1$ $d'_3d'_3$ ii and 25V112-2 D_1D_1 d_2d_2 d_3d_3 $D'_1D'_1$ $D'_3D'_3$ ii.

THREE-WAY CROSSES

Both Onas and Fawn are varieties that were introduced from Australia, while Kuangtoa and Peiteng are two indigenous varieties of Szechuan. Crosses between Onas and Fawn, Onas and Kuangtoa, and Peiteng and Fawn give no segregation in F_2. When F_1's of these three crosses were crossed to Quality, F_1's were normal and F_2's gave varying segregations, as shown in Table 8.

With the exception of the ratio 49:15, all other ratios can be explained on the assumption given above, and the possible factor interactions are given in the last column. Ratio 49:15 can be explained by the result of the interaction of one of the complementary factors with its duplicate factor and the inhibiting factor. Since Quality is homozygous for D_1 and D_3, and D'_1, the result of these three-way crosses indicates the segregation of D_2. Thus, the genotype of F_1 must be D_2d_2 $D'_2d'_2$ Ii, D_2, D'_2, and I must be contributed, therefore, by the parents other than Quality.

PROGENIES OF THE DWARFS

According to the assumption of the factor interaction for the segregation of dwarfs, the F_2 dwarf plants would have the following segregation ratios for dwarfs and normals in F_3:

Cross	Expected ratio: No segregation	Expected ratio: Segregation	Segregation ratios to be expected
Quality × P165	6	39	3:1, 9:7, 15:1 and 45:19
P165 × 25V112–1	1	26	3:1, 9:7, 27:37
P165 × 25V112–2	49	626	3:1, 15:1, 45:19, 225:31, 135:121 and 675:349

As mentioned earlier, the dwarfs yield none or a few seeds at the most per plant. There are altogether 25 lines that come from the above-stated three crosses. However, the number of plants in each line is too small to render a complete analysis of the results according to the assumptions made. Nevertheless, the results are given in Table 9 to show the mode of segregation of the progeny of F_2 dwarf plants in F_3.

It is apparent from the results that there are segregating and nonsegregating lines in existence. In the segregating lines, there are possibly various kinds of ratios for dwarfs and normals. This is in

TABLE 7.—*Mode of segregation for dwarfness in F_3 of some of the crosses.**

Number of sub-lines	Observed		Calculated		Calculated ratios, normal: dwarf	χ^2	Possible genotypes of the F_2 plants
	Normal	Dwarf	Normal	Dwarf			
12	744	141	739.16	145.84	3,421:675	0.193	D_1d_1 D_2d_2 D_3d_3 $D'_1d'_1$ $D'_3d'_3$ Ii
13	840	121	834.31	126.69	889:135	0.295	D_1d_1 D_2d_2 D_3d_3 $D'_1d'_1$ $d'_3d'_3$ Ii, etc.
8	593	157	585.21	164.79	799:225	0.472	D_1d_1 D_2D_2 D_3d_3 $D'_1d'_1$ $D'_3d'_3$ Ii
5	722	150	718.72	153.28	211: 45	0.085	D_1d_1 D_2d_2 D_dD_d $D'_1d'_1$ $d'_3d'_3$ Ii, etc.
17	1,296	125	1,271.13	149.87	229: 27	4.614	D_1d_1 D_2d_2 D_3d_3 $D'_1d'_1$ $d'_3d'_3$ Ii, etc.
1	85	26	84.98	26.02	49: 15	0.000	D_1d_1 D_2D_2 D_3D_3 $D'_1d'_1$ $d'_3d'_3$ Ii, etc.
6	579	93	577.50	94.50	55: 9	0.028	D_1d_1 D_2d_2 D_3D_3 $d'_1d'_1$ $d'_3d'_3$ Ii, etc.
5	313	75	315.25	72.75	13: 3	0.086	D_1d_1 D_2D_2 D_3D_3 $d'_1d'_1$ $d'_3d'_3$ Ii, etc.
4	264	102	274.50	91.50	3: 1	1.607	D_1d_1 D_2D_2 D_3D_3 $d'_1d'_1$ $d'_3d'_3$ Ii, etc.

*Pedigree Nos. 5, 11, and 14 of Table 6.

TABLE 8.—*Segregation in F_2 of various three-way crosses.*

Line No.	Cross	Observed		Calculated		Calculated ratio, normal : dwarf	χ^2	F_1 genotypes
		Normal	Dwarf	Normal	Dwarf			
1A1	(Onas×Fawn)×Quality	54	14	55.25	12.75	13: 3	0.151	D_2d_2 Ii
1A2	(Onas×Fawn)×Quality	224	49	221.81	51.19	13: 3	0.116	D_2d_2 Ii
1A3	(Onas×Fawn)×Quality	305	95	306.25	93.75	49: 15	0.022	D_2D_2 $D'_2d'_2$ Ii
3B1	(Onas×Kuangtoa)×Quality	114	19	114.30	18.70	55: 9	0.006	D_2d_2 D_3d_3 Ii
3B2	(Onas×Kuangtoa)×Quality	403	84	401.39	85.61	211: 45	0.036	D_2d_2 D_3d_3 $D'_3d'_3$ Ii
3B3	(Onas×Kuangtoa)×Quality	383	67	386.72	63.28	55: 9	0.255	D_2d_2 D_3d_3 Ii
3B4	(Onas×Kuangtoa)×Quality	all	0					
5A1	(Peiteng×Fawn)×Quality	188	51	194.19	44.81	13: 3	1.052	D^2d^2 Ii
5A2	(Peiteng×Fawn)×Quality	324	61	321.55	63.45	3,421:675	0.114	D_1d_1 D_2d_2 D_3d_3 $D'_1d'_1$ $D'_3d'_3$ Ii
5A3	(Peiteng×Fawn)×Quality	312	67	312.38	66.62	211: 45	0.003	D_2d_2 D_3d_3 D'_2d_2' Ii
5A4	(Peiteng×Fawn)×Quality	195	60	195.23	59.77	49: 15	0.001	$D'_2d'_2$ $D'_2d'_2$ Ii
5A5	(Peiteng×Fawn)×Quality	all	0					
5B1	(Peiteng×Fawn)×Quality	282	60	281.88	60.12	211:45	0.000	D_2d_2 D_3d_3 $D'_2d'_2$ Ii
5B2	(Peiteng×Fawn)×Quality	all	0					

accordance with our assumption. Since the number in each line is too small, further analysis is impossible.

TABLE 9.—*Segregation of F_2 dwarf plants in F_3.*

Line No.	Number of sub-lines	Observed	
		Dwarf	Normal
2G-3, 10, 11	3	31	0
2G-4	1	16	10
2G-5	1	3	14
2G-9	1	9	5
2G-13	1	1	1
2G-1	1	6	5
2G-2	1	5	4
2G-6	1	1	2
2G-7	1	3	2
2G-8	1	1	5
2G-12	1	3	2
5E-18, 20, 33	3	14	0
5E-15	1	26	3
5E-16	1	1	1
5E-17	1	21	0
5F-24	1	6	1
5F-25	1	11	10
5F-26	1	3	12
5F-30	1	48	4
5F-31	1	4	2
5G-19	1	17	0

The normals that segregate in F_3 from the F_2 dwarf plants will not segregate again according to our hypothesis, for the inhibitor I is lacking; its normal plant behavior is simply due to incompleteness of the complementary factors. Out of 45 normal plants thus obtained, all bred true for normals in F_4. However, three of them gave segregation in later generations for normals and dwarfs in ratios of 48:7, 39:6, and 20:4. The percentage of normals in these segregations indicates the presence of Ii segregation. Since I is not present in these normal plants according to our hypothesis, its presence would indicate stray pollination that occurs in the F_2 dwarf plants from which these normals are derived. This assumption is rather probable because foreign pollen carrying factor I can be easily lodged on the dwarf plant, thus facilitating cross pollination.

CROSSES BETWEEN DWARFS AND PURE LINE 2905

The dwarf plants used as parents in making the crosses come from the following sources:

1. Line 2G-3.—F_3 of the cross Quality and P165. There are 12 plants in this line. All are dwarfs.

2. Line 5E-15.—F_3 of the cross P165 and 25V112-1. There are 29 plants, 26 dwarfs and 3 normals.

3. Line 5E-17.—F_3 of the cross P165 and 25V112-1. All 21 plants are dwarfs.

By crossing dwarf plant in 2G-3 by the multiple recessive 2905, five F_1 plants were obtained, three of which were dwarfs and two normals. Nothing can be said about this ratio owing to the smallness of the number of plants obtained. However, the progenies of these dwarf plants will reveal their respective genic constitutions. Indirectly, it should verify further our assumption as to the genetical constitution of the parents from which these dwarf plants were derived. There are three possible genetical constitutions for the F_1 dwarf plants thus obtained, i.e., (A) D_1d_1 D_2d_2 D_3d_3 $d'_1d'_1$, (B) d_1d_1 D_2d_2 D_3d_3 $D'_1d'_1$, and (C) D_1d_1 D_2d_2 D_3d_3 $D'_1d'_1$. Both (A) and (B) should give dwarfs and normals in a 27:37 ratio, while (C) should give a 135:121 ratio. These are realized. Likewise, when the dwarf plant in line 5E-15 was backcrossed to 2905, 19 plants were obtained, 10 of which were dwarf and 9 normal. These dwarf plants must have the same genic constitution of D_1d_1 D_2d_2 D_3d_3. Progeny of these plants would give dwarf and normal plants in a 27:37 ratio. This is exactly the case. In the same way, by backcrossing dwarf plants in line 5E-17 to 2905, only two plants were obtained, one dwarf and another normal. Similarly, only one ratio, 27:37 was realized. These are shown in Table 10.

TABLE 10.—*Results of F_2 segregation of the crosses between dwarfs and pure line 2905.*

Line No.	Cross	Observed		Calculated		χ^2
		Dwarf	Normal	Dwarf	Normal	
				(135:121)		
1289-1	2G-3×2905	51	27	41.13	36.87	5.011
1289-2	2G-3×2905	21	13	17.93	16.07	1.112
				(27:37)		
1289-3	2G-3×2905	16	29	18.98	26.02	0.809
1299-2	5E-15×2905	79	85	69.19	94.81	2.406
1299-3	5E-15×2905	23	42	27.42	37.58	1.232
1301-1	5E-15×2905	86	131	91.55	125.45	0.582
1301-2	5E-15×2905	38	55	39.23	53.77	0.067
1302	5E-15×2905	23	21	18.56	25.44	1.837
1303-1	5E-15×2905	36	60	40.50	55.50	0.865
1303-2	5E-15×2905	86	96	76.78	105.22	1.915
1303-3	5E-15×2905	11	16	11.39	15.61	0.023
1305	5E-17×2905	17	29	19.41	26.59	0.517

DISCUSSION

From the results obtained, the genetical constitution of the parents used can be assigned, as given in Table 11.

It is realized that the experimental data are far from complete. However, as far as the results are concerned, they all appear to be quite consistent with our hypothesis. Further verification is under way especially in the isolation of various testers.

It is of great interest to obtain data indicating the existence of complete set of duplicate factors for the respective three complementary factors D_1, D_2, and D_3 for the expression of dwarf plants in the various crosses. Duplicate factors in wheat have been obtained previously for the inheritance of grain color and other characters. This is due to the polyploid nature of the wheat plant. Probabilities are rather high that these duplicate factors occur in three different genoms each of which has seven chromosomes. The genetical results thus substantiate the cytological finding.

TABLE 11.—*Possible genotypes of the parents used.*

Variety	Complementary factors*			Duplicate factors*			Inhibitor I*
	D_1	D_2	D_3	D'_1	D'_2	D'_3	
Quality	+	−	+	+	−	−	−
P165	−	+	+	−	−	−	+
25V112-1	+	−	−	−	−	−	−
25V112-2	+	−	−	+	−	+	−
2905	−	−	−	−	−	−	−
Mo's 101	−	+	−	−	−	+	+
Noogaar	+	+	+	−	−	−	+
Fawn	+	+	+	−	−	−	+
Florence	+	+	+	−	−	−	+
Majestic	±	+	±	+	−	+	+
Marshall's No. 3	±	+	±	+	−	+	+
Onas	±	−	+	+	+	±	+
Purplestraw	±	+	+	+	−	±	+
Rajah	±	+	+	+	−	±	+
Omaral	±	+	+	+	−	±	+
7L1	−	−	−	+	−	+	−
6L1	−	−	−	+	−	+	−
Kuangtoa	−	−	±	−	−	±	+
Peiteng	−	−	−	−	+	−	+

*+ Denotes the presence of dominant gene; − denotes the presence of recessive gene; ± denotes uncertainty.

According to our hypothesis, the appearance of dwarf plants would be obtained from an interaction of three complementary factors D_1, D_2, and D_3. Some chemical product must be produced from three successive processes to which each gene would play a part. The chemical product thus produced would hinder the normal growth of the plant resulting in dwarfness. In Zea, the dwarf type of plant nana is a monogenic recessive. It is characterized by the ability of its tissues to inactivate auxin by oxidation at an excessive rate as compared with the tissues of normal plants (2,3). Whether the interaction of these complementary factors in wheat would produce some chemical product which would inhibit a growth hormone like auxin or whether this chemical product is a hormone of some kind that hinders the normal growth of the plant is not known.

The action of an inhibitor may prevent normal development of one of the successive processes of the three complementary genes. It may inhibit or overcome the final chemical product of these processes. No

matter how and when it functions, the final outcome will be the same. That is, the plant will be of normal growth.

SUMMARY

Dwarf wheat plants were first obtained in F_2 of crosses between Quality and P165 and between P165 and 25V112. They were also found in other crosses later. From the mode of segregation, the results can be explained on the assumption of an interaction of three complementary factors, D_1, D_2, and D_3, and two duplicate factors, D'_1 and D'_3, with an addition of an inhibitor, I. The presence of all three complementary factors or a substitute of its respective duplicate factor is necessary for the manifestation of dwarf plants. The recessive condition of one of these three essential factors will give a normal plant. The presence of the inhibitor I in the presence of the three essential factors for dwarf plants also results in the production of normal plants. This assumption is substantiated further by F_3 data, by data obtained in progenies of dwarf plants, and by data obtained from crossing dwarf plants to the multiple recessive stock 2905. Duplicate factor D'_2 is postulated in explaining the results obtained from crossing (Onas × Fawn) to Quality and (Peiteng × Fawn) to Quality. Altogether there are three basic complementary factors, D_1 D_2 D_3, three duplicate factors, D'_1 D'_2 D'_3, and an inhibitor, I, that have been used to account for the genetical explanation of dwarfness in wheat. The probable genetical constitution of the different parents used is tabulated.

LITERATURE CITED

1. KIHARA, H. Investigation of wheat. Tokyo. 1938. (In Japanese). See pages 388–392.
2. VAN OVERBEEK, J. Auxin production in seedlings of dwarf maize. Plant Physiol., 13:587–598. 1938.
3. ———. "Laziness" in maize due to abnormal distribution of growth hormone. Jour. Heredity, 29:339–341. 1938.

THE LINKAGE RELATIONS OF FOUR GENES IN CHROMOSOME I OF BARLEY[1]

S. P. SWENSON AND DARRELL G. WELLS[2]

THE arrangement of several genes in chromosome I of barley has been determined by Robertson (6),[3] Robertson and Coleman (7, 8), and Immer and Henderson (3). It is the purpose of this paper to present the results of an analysis of the linkage relations of four gene pairs in chromosome I, non-six-rowed vs. six-rowed spikes (*Vv*), awnless vs. awned outer glumes (*E e*), tall vs. short plants (*H h*), and high vs. low number of rachis internodes (*Rin rin*).

The arrangement of *V v* and *E e* with regard to other genes already has been set forth by the afore-mentioned authors. Linkage between a gene or genes for plant height and *V v* has been reported previously by Miyake and Imai (4), Tedin and Tedin (11), and Neatby (5). A gene differentiating high and low number of rachis internodes was found by Tavcar (10) to exhibit 32.9% recombination with *V v*. Whether the *H h* and *Rin rin* gene pairs discussed in this paper are the same as those for plant height and number of rachis internodes studied by previous workers has not been ascertained.

In this study, the loci of *H h* and *Rin rin* have been determined and indicated on the chromosome map. The symbols used are those recommended by Robertson, Wiebe, and Immer (9).

MATERIALS AND METHODS

The data for this study were obtained from the cross Spartan × Triple Bearded Mariout (C.I. 2523), made originally as one of a series of crosses for cataloguing genes determining outer glume characters. Spartan is a commercial variety grown in Michigan and the Northern Great Plains, and C.I. 2523 was obtained from G. A. Wiebe. Spartan has non-six-rowed spikes of the *Hordeum deficiens* type, awnless outer glumes, medium tall plants, and an intermediate number of rachis internodes, while C.I. 2523 has six-rowed spikes, awned outer glumes, short plants, and a low number of rachis internodes. Therefore, all of the six possible combinations of gene pairs are in coupling phase.

While a population of 100 F_3 lines of 40 to 50 plants each was being grown in 1941, segregation and linkage of the four pairs of characters were noted. At harvest, all F_3 plants were classified into four height classes, based on actual measurements of individual plants from four rows of each parent and one row of 20 F_1 plants. After the plants of an F_3 line had been divided into classes, one typical spike was taken from each plant and placed in a paper carton with other spikes from the same class and line. Thus, one to four cartons of spikes were obtained from a line, depending on the range of segregation for plant height within the line. The contents of each carton were classified later in the laboratory for type of spike, type of glume, and number of rachis internodes.

In 1942, 405 additional F_3 lines of approximately 50 plants each were grown from the remaining F_2 plants which were available. Parent checks were grown every 30 rows. All lines were classified from standing plants in the field as homozygous dominant, segregating, or homozygous recessive for each of the four charac-

[1]Published as Scientific Paper No. 587, College of Agriculture and Agricultural Experiment Stations, State College of Washington, Pullman, Wash. Received for publication January 8, 1944.

[2]Associate Geneticist and Assistant in Agronomy, respectively. The authors are indebted to Miss Shirley Kellenbarger for her aid in making the computations.

[3]Figures in parenthesis refer to "Literature Cited", p. 435.

ters. However, before they were classified for plant height and number of rachis internodes, actual measurements and counts were made from individual plants in all of the parent rows. With the information thus obtained at hand, it was possible by making sample measurements or counts to determine the F_2 genotype from which each F_3 line was derived.

The percentages of recombination were derived by the method of maximum likelihood outlined by Immer (2) and Immer and Henderson (3). Both the F_2 genotypes and F_2 phenotypes as determined from F_3 data were used in the calculations. The first approximation was obtained from the F_2 phenotypic ratios, using the product method discussed by Immer (1).

EXPERIMENTAL RESULTS

The observed ratio of F_2 genotypes as determined from F_3 data for non-six-rowed vs. six-rowed spikes was 116 *V V*:249 *V v*:140 *v v* and for awnless vs. awned outer glumes, 143 *E E*:231 *E e*:131 *e e*. When tested for goodness of fit to a 1:2:1 ratio, P values of .30 and .20-.10, respectively, were obtained. These results are in accord with those of previous workers cited by Robertson, Wiebe, and Immer (9).

The data on the inheritance of plant height are given in Tables 1, 2, and 3. Table 1 is a summary of the measurements of individual plants of the parents and F_1 grown in 1941, presented to show how the four classes for height were derived from the parental and F_1 ranges. Practically no over-lapping of the two parental ranges occurred and tall apparently is dominant over short. Each parental range was divided into two equal portions except in the case of Spartan where class 4 was extended from 45 to 48 inches to accommodate occasional F_3 plants which were slightly taller than Spartan.

TABLE 1.—*Summary of measurements of height in inches of plants of Spartan, C.I. 2523, and the F_1 grown in 1941, showing how four classes for plant height were derived from the parental ranges.*

Item	No. of plants in indicated classes for plant height				No. of plants	Mean height, in.	Range, in.
	4 41–48 in.	3 33–40 in.	2 25–32 in.	1 16–24 in.			
Spartan	63	109	—	—	172	39.0	33–45
C.I. 2523	—	3	139	27	169	26.4	16–32
S×C.I. 2523, F_1	7	13	—	—	20	38.3	34–41

TABLE 2.—*The distribution of parent and F_1 rows and F_3 lines grown in 1941 according to range in height of plants classified into the four classes indicated in Table 1.*

Item	No. of rows or lines in indicated ranges of plant height										No. of rows or lines
	4	4–3	3	4–2	4–1	3–2	3–1	2	2–1	1	
Spartan, rows	—	4	—	—	—	—	—	—	—	—	4
C.I. 2523, rows	—	—	—	—	—	—	1	—	3	—	4
S×C.I. 2523, F_1 row	—	1	—	—	—	—	—	—	—	—	1
S×C.I. 2523, F_3 lines	—	20	1	40	6	16	13	3	1	—	100

TABLE 3.—*The distribution and frequencies of F_3 lines grown in 1941 and 1942, according to F_2 genotypes for plant height, and the P values for X^2 tests for goodness of fit.*

Year	No. of F_3 lines from indicated genotypes			No. of lines	P from χ^2
	H H	*H h*	*h h*		
1941.........	33	44	23	100	.20–.10
1942.........	86	222	97	405	.20–.10
Total........	119	266	120	505	.50–.30

The classes used in Table 2 indicate the ranges in plant height for different F_3 lines and for parent and F_1 rows grown in 1941. The recovery of only four F_3 lines in the last three classes suggests that two gene pairs govern plant height. If one main pair, *H h*, and a modifier pair, H_1h_1, are postulated, the data agree with a two-gene hypothesis reasonably well. *H* is assumed to produce tall plants whose heights are only slightly depressed in the absence of H_1, and H_1 is assumed to add slightly, but noticeably, to the height of the short *h h* plants. One fourth of the F_3 lines are expected to breed true for tall plants, being homozygous for *H H*; however, *H H* lines carrying H_1h_1 or h_1h_1 may contain occasional plants in class 2. Likewise, *h h* lines are expected one-fourth of the time, but those carrying H_1H_1 or H_1h_1 should contain plants in class 3. The remaining half of the lines may be expected to segregate for tall and short plants in a ratio approximating 3:1.

Twelve of the lines in class 4-2 consisted of plants predominantly in classes 4 and 3 with occasional plants in class 2. These 12 lines are assigned to the *H H* genotype with the 21 lines from classes 4-3 and 3 to make a total of 33 *H H* lines. Nine lines in class 3-2 exhibited excesses of plants in class 2 and were allotted to the *h h* genotype. A similar disposition was made of 10 of the lines in class 3-1 since most of the plants occurred in classes 2 and 1. Thus, a total of 23 lines are designated as *h h* .The segregation within the remaining 44 lines indicated that they might be logically classified as originating from the *H h* genotype.

The resulting ratio of 33 *H H* : 44 *H h* : 23 *h h* exhibits a satisfactory fit to a 1:2:1 ratio, as shown in Table 3. When the 1941 and 1942 data are combined, the resulting ratio agrees very well with expectation.

The analysis of rachis internode numbers is similar to that for plant height. The summary of counts presented in Table 4 for the parents and F_1 grown in 1941 shows that very little overlapping occurred between the parental ranges and that high internode number is dominant over low.

Only six F_3 lines are recovered within the range of the low parent, suggesting that two gene pairs also are involved for rachis internode number. A hypothesis similar to that for plant height appears to explain the results satisfactorily. *Rin* produces a high number of internodes which is slightly reduced in the absence of Rin_1. Rin_1 adds from two to four internodes in the presence of *rin rin*. Consequently, one-fourth of the F_3 lines should carry *Rin rin* and breed true

for high internode number, but those carrying Rin_1 rin_1 or rin_1 rin_1 may show occasional plants in the 18 and 16 internode classes. In a similar manner, one-fourth of the lines should contain all *rin rin* plants; however, occasional plants with 22 or even 24 rachis internodes may be expected from lines carrying Rin_1 Rin_1 and Rin_1 rin_1. The remaining half of the lines should segregate approximately 3:1 for high and low internode number.

TABLE 4.—*Summary of counts of rachis internode numbers of Spartan, C. I. 2523, and the F_1 grown in 1941.*

Item	No. of plants with indicated rachis internode numbers									No. of plants	Mean No. of inter-nodes	Range
	28	26	24	22	20	18	16	14	12			
Spartan........	4	19	56	66	23	3	—	—	—	171	22.9	18–28
C.I. 2523.......	—	—	—	—	2	26	65	60	14	167	15.3	12–20
S×C.I. 2523, F_1.	—	2	9	2	2	—	—	—	—	15	23.5	20–26

Seven of the 27 lines in class 16 or above in Table 5 consisted largely of plants having 18 or more internodes with only occasional plants in the 16 internode class. These 7 lines plus the 20 which occurred in the first two classes are assigned to the *Rin Rin* genotype. The 4 lines with internode numbers of 22 or less, and 12 of the 18 lines with 24 or less, were designated as *rin rin* because of the predominance of plants with 20 or less internodes. Thus, 22 lines are attributable to the *rin rin* genotype. The remaining 51 lines are classified as *Rin rin*.

The resulting ratio of 27 *Rin Rin* : 51 *Rin rin* : 22 *rin rin* agrees very satisfactorily with expectation as shown in Table 7. The 1942 data and the totals for the two years also exhibit good agreement.

The ratios of F_2 genotypes determined from F_3 data and the recombination percentages for the six possible combinations of the four gene pairs are presented in Table 6. All of the recombination percentages were obtained as a result of adding the information from doubly dominant and singly dominant F_2 genotypes, and from the F_2 phenotypes ascertained from the F_3 data. Except for the *V v E e* combination, the classifications within lines, made in 1941, were not considered usable for calculating recombination percentages because of the uncertainties associated with the quantitative nature of the segregation for *H h* and *Rin rin*. Consequently, no attempt was made to separate the double heterozygotes into those arising from coupling or repulsion, nor were the phenotypic ratios from within such lines used as F_2 data in arriving at the recombination percentages shown in Table 6. When these data from the *V v E e* combination were included, the recombination percentage became $30.0 \pm 1.1\%$.

A good agreement of the observed with the expected ratios, calculated from the indicated recombination percentages, was obtained in four of the six combinations. The *Rin rin E e* and *H h E e* combinations exhibit rather low P values. For *Rin rin E e* there is a deficiency of lines observed in the m class, while for *H h E e* there are deficiencies in classes g and j and an excess in class f. These discrepancies prob-

TABLE 5.—*The distribution of parent and F_1 rows and F_3 lines grown in 1941 according to range in rachis internode number.*

Item	No. of rows or lines in indicated ranges of rachis internode numbers										No. of rows or lines
	20 or above	18 or above	16 or above	30 to 14 or below	28 to 14 or below	26 to 14 or below	24 to 14 or below	22 or below	20 or below	18 or below	
Spartan, rows	2	2	—	—	—	—	—	—	—	—	4
C.I. 2523, rows	—	—	—	—	—	—	—	—	1	3	4
S×C.I. 2523, F_1 row	1	—	—	—	—	—	—	—	—	—	1
S×C.I. 2523, F_3 lines	7	13	27	1	5	19	18	4	4	2	100

TABLE 6.—*The distribution and frequencies of F_3 lines grown in 1941 and 1942 according to F_2 genotypes, the percentages of recombination, and the P values from X^2 tests for goodness to fit to ratios calculated from the recombination values for the six possible combinations of the gene pairs, V v, Rin rin, H h, and E e.*

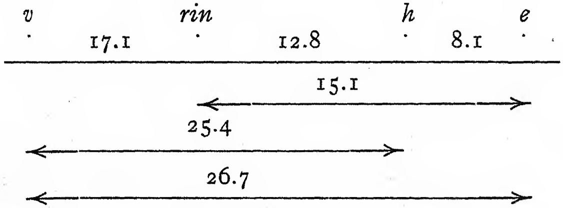
Gene pairs				Number of lines in indicated classes									Percentage recombination	P_2 from χ^2 for goodness of fit
X	x	Y	y	XXYY e	XxYY f	XXYy g	XxYy h+i	XXyy j	Xxyy k	xxYY l	xxYy m	xxyy n		
V	*v*	*Rin*	*rin*	84	38	29	185	3	26	5	52	83	17.1±1.3	0.20–0.10
V	*v*	*H*	*h*	64	46	48	158	4	45	9	60	71	25.4±1.6	0.70–0.50
V	*v*	*E*	*e*	73	57	36	141	7	51	13	54	73	26.7±1.7	0.50–0.30
Rin	*rin*	*H*	*h*	90	26	34	210	3	30	4	21	87	12.8±1.1	0.50–0.30
Rin	*rin*	*E*	*e*	96	41	36	191	5	34	6	14	92	15.1±1.2	0.05–0.01
H	*h*	*E*	*e*	110	31	8	213	1	22	2	10	108	8.1±0.9	0.01

ably are attributable to errors in classification made in the field in 1942. However, the P values are not beyond the realm of probability. Since there is no opportunity for reclassification, the obtained recombination percentages must be accepted as the best available for this study.

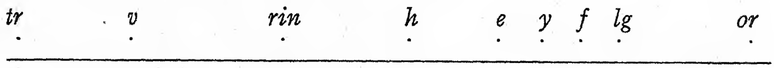
TABLE 7.—*The distribution and frequencies of F_3 lines grown in 1941 and 1942 according to F_2 genotypes for rachis internode number, and the P values from X^2 tests for goodness of fit.*

Year	No. of F_3 lines from indicated genotypes			No. of lines	P from χ^2
	Rin Rin	*Rin rin*	*rin rin*		
1941.......	27	51	22	100	.95–.50
1942.......	100	215	90	405	.60–.50
Total.......	127	266	112	505	.60–.50

From the obtained results, the arrangement of the four genes is as follows:



Immer and Henderson (3) combined their own data for normal vs. triple awned lemma (*Tr tr*), non-six-rowed vs. six-rowed spikes (*V v*), awnless vs. awned outer glumes (*E e*), normal vs. virescent seedlings (*Y y*), and green vs. light green seedlings (*Lg lg*) with data from Robertson and Coleman (7, 8) for green vs. chlorina seedlings (*F f*) and green vs. orange seedlings (*Or or*) to arrive at the order *tr – v – e – y – f – lg – or* for the seven genes. The addition of *rin* and *h* from the present study increases the number of mapped genes to nine and results in the following arrangement:



SUMMARY

The inheritance and linkage relations of tall vs. short plants and high vs. low number of rachis internodes were studied in relation to two known marker gene pairs in chromosome I of barley, non-six-rowed vs. six-rowed spikes (*V v*) and awnless vs. awned outer glumes (*E e*).

Plant height was found to be governed by one main gene pair, *H h*, and a modifier pair, H_1 h_1. However, *H h* could be satisfactorily isolated so its linkage relations could be studied.

Rachis internode number also was conditioned by one main gene pair, *Rin rin*, and a modifier pair, Rin_1 rin_1. Furthermore, *Rin rin* could be isolated for a study of its linkage relations.

The order and recombination percentages of the four genes were found to be $v - 17.1 - rin - 12.8 - h - 8.1 - e$. The addition of *rin* and *h* to the map of chromosome I increases the number of mapped genes to nine which occur in the order $tr - v - rin - h - e - y - f - lg - or$.

LITERATURE CITED

1. IMMER, F. R. Formulae and tables for calculating linkage intensities. Genetics, 15:81–98. 1930.
2. ————. Calculating linkage intensities from F_3 data. Genetics, 19:119–136. 1934.
3. ———— and HENDERSON, M. T. Linkage studies in barley. Genetics, 28:419–440. 1943.
4. MIYAKE, K. and IMAI, Y. Genetic studies in barley, I. Bot. Mag. (Tokyo), 36:25–38. 1922.
5. NEATBY, K. W. An analysis of the inheritance of quantitative characters and linkage in barley. Sci. Agr., 9:701–718. 1929.
6. ROBERTSON, D. W. Genetics of barley. Jour. Amer. Soc. Agron., 4:273–283. 1939.
7. ———— and COLEMAN, O. H. The addition of two factor pairs for chlorophyll deficient seedlings to the linkage groups of barley. Jour. Genetics, 39:401–410. 1940.
8. ————, ————. Location of glossy and yellow seedlings in two linkage groups. Jour. Amer. Soc. Agron., 34:1028–1034. 1942.
9. ————, WIEBE, G. A., and IMMER, F. R. A summary of linkage studies in barley. Jour. Amer. Soc. Agron., 33:47–64. 1941.
10. TAVCAR, ALOIS. Vererbungsart der Spindelstufenzahl bei Bastardierungen einiger *distichum* × *vulgare* Wintergersten. Ztschr. f. Induktive Abstam. u. Vererbungslehre, 75:106–123. 1938.
11. TEDIN, H., and TEDIN, O. Contribution to the genetics of barley I. Type of spike, nakedness and height of plant. Hereditas, 7:151–160. 1926.

AGE OF SEED CORN IN RELATION TO SEED INFECTION AND YIELDING CAPACITY[1]

George H. Dungan and Benjamin Koehler[2]

FREQUENTLY corn growers and seedsmen have seed corn left over from one planting season to another. New seed, especially of hybrid corn, is costly and frugality tempts the use of this seed for planting. Not only does viable seed contain a live embryo, but frequently it is also parasitized by fungi that may become more or less harmful after planting, the degree depending much on environmental conditions and whether or not the seed is treated with a suitable disinfectant. Studies are reported here on the effect of aging on both the embryo and fungus infection.

LONGEVITY OF FUNGUS INFECTION WITHIN CORN GRAINS

Corn seed infection by a number of fungi is very common in ears that have been left to cure on the stalks in the field and under some seasonal conditions is prevalent also in seed that has been harvested early and processed by modern technic. Practically nothing has been known about the longevity of such infection. Shands (5)[3] has pointed out that *Gibberella zeae* (*G. saubinetii*) is short-lived in infected barley kernels, living a maximum of 27 months after harvest, while a number of other fungi are much longer lived.

TECHNIC AND STORAGE CONDITIONS

In 1931, about 3,000 ears of the Illinois Experiment Station strain of Reid Yellow Dent corn (hereafter called Station Yellow Dent) that had been selected as desirable for seed ears were tested on a germinator (3) for viability and fungus infection. Infected ears were classified separately according to the kind of infection present. These ears were then retested by the petri dish method. The latter method revealed only internal infection because external organisms were killed by surface sterilization, but it is better than the germinator method for positive identification of the organisms and for making reasonably sure that the kernels on an ear are infected by only one kind of fungus. Twenty kernels from each ear were used for the petri dish test.

In the final selection there were five groups of ears, each group infected with a different fungus, and 7 to 30 ears in each group. After shelling, 30 representative samples of 100 kernels each were prepared from each of the five groups for periodic testing. Two samples (200 kernels) were taken at random from each group for each test. Periodic tests for viability were made on a germinator without the use of surface disinfection. In tests for longevity of internal infection the kernels were surface sterilized with a 2% sodium hypochlorite solution for 30 minutes and placed on potato dextrose agar medium.

The seed packages were stored in a covered tin box which was kept in the laboratory at ordinary room temperature. Some moth balls were kept in the box to guard against insect damage. The moisture in the grain came to an equilibrium with the atmosphere at about 10.5%.

---

[1]Contribution from the Department of Agronomy, Illinois Agricultural Experiment Station, Urbana, Ill., and published with the approval of the director. Also presented at the annual meeting of the Society in Cincinnati, Ohio, November 12, 1943. Received for publication January 13, 1944.

[2]Chief in Crop Production and Chief in Crop Pathology, respectively.

[3]Figures in parenthesis refer to "Literature Cited", p. 442.

RESULTS

An appreciable percentage of the seed was still alive after all fungus life within the seeds had died (Table 1). Only in the case of *Gibberella zeae* could one expect almost complete elimination of infection when seed is held over for a year, which makes the actual age of the seed at planting time about 19 months. Under good storage conditions this delay in planting usually has very little advserse effect on the viability of the seed. Gibberella-infected seed has been observed to improve in germination after it has been stored for 1 year. *Nigrospora oryzae* (B. and Br.) Petch infection also was greatly reduced by holding for a year, and *Diplodia zeae* infection was reduced by about 50%. Diplodia infection persisted in diminishing amounts for 6 years. *Cephalosporium acremonium* Corda and *Fusarium moniliforme* Sheldon were longest lived, some traces remaining up to 7 and 8 years, but by the third year there already was a big drop in the percentage of infection compared with the initial percentage.

TABLE 1.—*Longevity of corn seed and of fungus infection within the seed (Station Yellow Dent Corn), 1931 crop, Agronomy South Farm, Urbana, Ill.*

Fungus infection in seed sample	Percentage viability of seed after storage periods of			Percentage of kernels carrying live fungus infection after storage periods of										
	3 mos.	5 yrs.	10 yrs.	3 mos.	15 mos.	2 yrs.	3 yrs.	4 yrs.	5 yrs.	6 yrs.	7 yrs.	8 yrs.	9 yrs.	10 yrs.
Cephalosporium acremonium	98.5	91.5	14	73.0	68.0	67.5	16.0	9.5	2.5	0	0.5	0	0	0
Diplodia zeae	85.0	82.5	23	58.5	27.5	17.5	12.5	7.0	5.5	1.0	0	0	0	0
Fusarium moniliforme	98.0	88.0	26	49.5	35.5	28.5	9.5	4.0	1.5	2.0	0.5	0.5	0	0
Gibberella zeae	87.5	80.0	11	48.0	2.0	0	0	—	—	—	—	—	—	—
Nigrospora oryzae	95.0	84.5	32	53.0	12.0	3	0	0	—	—	—	—	—	—

Under different storage conditions the results, of course, might have been different.

With respect to *Diplodia zeae* (Schw.) Lev. and *Gibberella zeae* (Schw.) Petch, infection was quite definitely limited to vegetative mycelium. Pycnidia or perithecia of these fungi develop only on grain that is in advanced stages of rot. It is possible that spores in these fruiting structures would have lived longer. While *Gibberella zeae* produces conidia under suitable culture conditions, these have not been found on infected seed corn. The other three fungi (Table 1) may possibly have developed a few spores in the cavity beneath the tip cap, but this also is not common in well-developed grain free from visible blemishes, and the infection probably existed primarily as mycelium.

CONCLUSIONS

Viability of *Gibberella zeae* in seed corn as it ages is lost more quickly than that of the embryo of the kernel. It is possible for 2-year-old seed infected originally with this organism to have greater value for planting than new seed of the same original quality. The same tendency operates in the case of seed corn infected with *Nigrospora oryzae* and *Diplodia zeae*, though to a lesser extent.

INFLUENCE OF AGE OF SEED CORN UPON FIELD PERFORMANCE

Robertson, Lute, and Kroeger (4) reported that seed corn stored under Colorado conditions retained its viability remarkably well, germinating as high as 32% after 21 years. Kiesselbach (2) found that well-matured, properly stored seed corn gave satisfactory yields when it was 4 years old. Climate, especially the humidity of the atmosphere in which seed is stored, is believed to play an important role in the retention of its viability and plantlet vigor. Tests reported earlier (1) and herein were conducted under the relatively humid environment of central Illinois.

KIND OF CORN USED AND STORAGE CONDITIONS

The principal corn used in this experiment was Station Yellow Dent of the highest quality obtainable. It was plant selected, stored on hangers where rapid drying would take place, and germinated for the selection of ears carrying vigorous nearly disease-free kernels. Also, seed of 11 different hybrids was used, namely, Illinois Hybrids 21, 200, 201, 206, 212, 751, 784, 805, 863, 877, and 947. The seed represented commercial quality and was grown and processed by mid-size seed-producing firms.

Shelled seed of the various lots was treated with an organic mercury dust disinfectant and stored in cloth bags which were kept in small-sized galvanized iron garbage cans. The samples were housed on the second floor of a brick building which was heated during the cold days of winter to a temperature of approximately 55° F. The moisture content of the corn in storage was approximately 10%. The conditions were believed to be typical of those that commonly occur in a corn belt seed-producing plant.

The lots of seed corn produced in different years were planted three kernels per hill in plots two rows wide and 10 hills long, randomized in blocks, and replicated four times in some years and nine times in others. In 1942 a duplicate planting was made dropping six kernels per hill and later thinning to two plants per hill. A perfect stand was thus obtained and the yielding ability of plants from old seed could be compared with that of plants from 1-year-old seed. Seed produced the previous season has been designated 1-year-old, although in reality only about 7 months had elapsed between the time of its maturity and planting time.

INFLUENCE OF AGE OF SEED ON YIELD OF GRAIN

In order to eliminate variation in yield levels in different years, yields shown in Table 2 and Fig. 1 have been expressed as a percentage of the yield produced by 1-year-old seed. The values thus obtained have been averaged and compared with those for 1-year-old seed for the same years. The average yields from seed of different ages have each been compared separately with that obtained from 1-year-old seed and the significance of the mean difference was measured by a determination of the "t" value. Significant differences are indicated by a single asterisk; highly significant differences by a double asterisk.

TABLE 2.—*Relative yield of shelled corn as influenced by age of seed (Station Yellow Dent), Agronomy South Farm, Urbana, Ill.*

Age of seed at time field test was made, years	Yield expressed as percentage of that produced by 1-year-old seed							Mean difference compared with yield from 1-year-old seed, %
	1936	1937	1938	1939	1940	1941	1942	
1	100.0	100.0	100.0	100.0	100.0	100.0	100.0	—
2	114.2	98.8	98.8	96.1	102.9	94.2	97.7	+0.4
3	98.4	97.5	98.8	92.6	113.7	82.4	92.1	− 3.5
4	94.3	97.5	86.8	94.2	108.7	89.1	90.4	− 5.6
5	—	94.4	95.9	82.6	101.4	66.8	77.4	−13.6*
6	—	—	91.3	91.7	93.3	78.0	70.4	−15.1**
7	—	—	—	76.9	83.2	29.7	68.3	−35.5**
8	—	—	—	—	54.8	34.8	23.8	−62.2**
9	—	—	—	—	—	26.7	20.5	−76.4**
10	—	—	—	—	—	—	18.9	−81.1**
100% yield, bu.	31.6	78.5	99.2	105.1	48.2	80.8	109.3	

*Exceeds the 5% point.
**Exceeds the 1% point.

Yields obtained from 2-year-old seed were as good as from 1-year-old seed. Yields from 3-year-old seed were 3.5% under and those from 4-year-old seed 5.6% under 1-year-old seed, though not signifi-

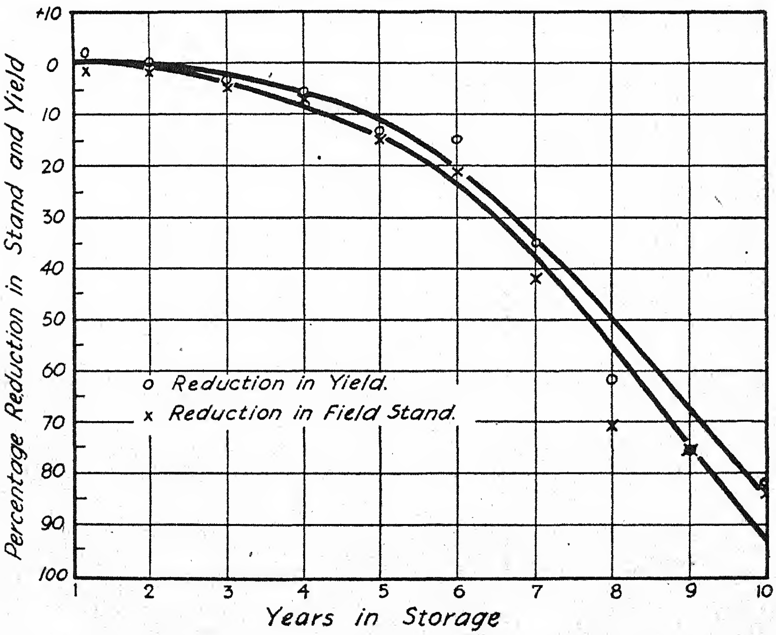


FIG. 1.—Percentage reduction in yield of grain and field stand resulting from aging of seed corn.

cantly less. Five-year-old seed yielded 13.5% less than 1-year-old seed, a significant reduction. Yields continued to decline with increasing age of seed, the decrease being sharp after the sixth year.

As noted above, the Station Yellow Dent seed used in these tests was of excellent quality. Four-year-old seed of this variety was not significantly inferior to 1-year-old seed. It was processed by hand methods which are not employed commercially in the processing of hybrid seed corn.

In order to determine if these results were applicable to hybrid corn, 18 replicated tests were made of 1-year-old and 2-year-old hybrid seed corn, and nine comparisons were made of 1-year-old and 3-year-old hybrid seed corn. The results show a reduction of 5.5% for 2-year-old seed and 8.7% for 3-year-old seed. Both differences are highly significant statistically.

REDUCTION OF FIELD STAND

Reduction in yields from old seed is attributable to low viability of the seed resulting in poor field stands, and also to a lessened vigor of the surviving seedlings. Germination tests in the laboratory show percentage viability, but conditions for seedling development in the field are seldom as favorable as on a germinator. In order to obtain data on the capacity of seed of different ages to produce plants under field conditions, a count was made each year before the first cultivation and the percentage stand calculated with the number of kernels planted as the base.

Data on percentage stand of Station Yellow Dent seed corn ranging in age from 1 to 10 years are shown in Table 3 and Fig. 1. No significant reduction in stand was found in the case of the 2- and 3-year-old seed. In the 4-year-old seed a significant reduction of 6.8% was obtained. Falling off in stand was gradual, though at an increasing rate, until the sixth year was passed when the drop in stand was sharp.

TABLE 3.—*Field stand of corn as influenced by age of seed (Station Yellow Dent), Agronomy South Farm, Urbana, Ill.*

Age of seed at time field test was made, years	Year and percentage stand							Mean difference, %
	1936	1937	1938	1939	1940	1941	1942	
1	92.6	91.7	93.8	98.0	94.0	91.3	95.3	—
2	87.4	95.6	90.7	96.3	93.3	87.7	93.3	1.8
3	93.7	95.7	91.6	96.0	85.2	74.3	89.0	4.4
4	91.1	93.2	78.3	86.8	89.3	76.0	94.0	6.8*
5	—	92.5	86.2	87.0	74.5	62.7	76.7	14.1*
6	—	—	79.7	90.1	55.3	71.3	68.7	21.5**
7	—	—	—	86.5	39.0	24.0	58.7	42.4**
8	—	—	—	—	25.0	25.7	17.3	70.9**
9	—	—	—	—	—	18.3	15.7	76.3**
10	—	—	—	—	—	—	12.7	82.6**

*Exceeds the 5% point.
**Exceeds the 1% point.

REDUCTION IN PLANT VIGOR

As illustrated in Fig. 2, it has been noted during the tests on age of seed corn that plants from old seed lacked the vigor of plants from new seed. In order to determine the extent of yield reduction due to decline in plant vigor of old seed, a test was conducted in 1942 involving Station Yellow Dent. The results are shown graphically in Fig. 3. Three-year-old seed averaged 4.8% lower in yield than 1-year-old seed when both lots had a perfect stand. When the number of kernels planted was uniform and no adjustment was made in stand, 3-year-old seed yielded 7.8% under 1-year-old seed. At the end of 7 years, reductions in yields were 10.1 and 31.7%, respectively, for the perfect stand and thin stand of old corn. These data suggest that during the first few years of aging the loss of plant vigor is about as important as reduction in stand, but as aging continues the loss of plant population is the more important factor in yield reduction.

FIG. 2.—Influence of age of seed on the vigor of corn plants. The row on the left is from seed produced the previous year, 1-year-old seed; that on the right is from 5-year-old seed.

CONCLUSIONS

Nearly disease-free seed corn, selected carefully and processed by hand methods, retains its viability and vigor so well as to produce practically as good yields when 3 years old as when new. Average seed corn produced commercially loses its yielding ability so rapidly with age that significant under-production will result. For the farmer using average commercial seed and interested in getting maximum returns or for the investigator comparing the yielding ability of different corn hybrids, it is unwise to use any other than seed of the previous season's crop.

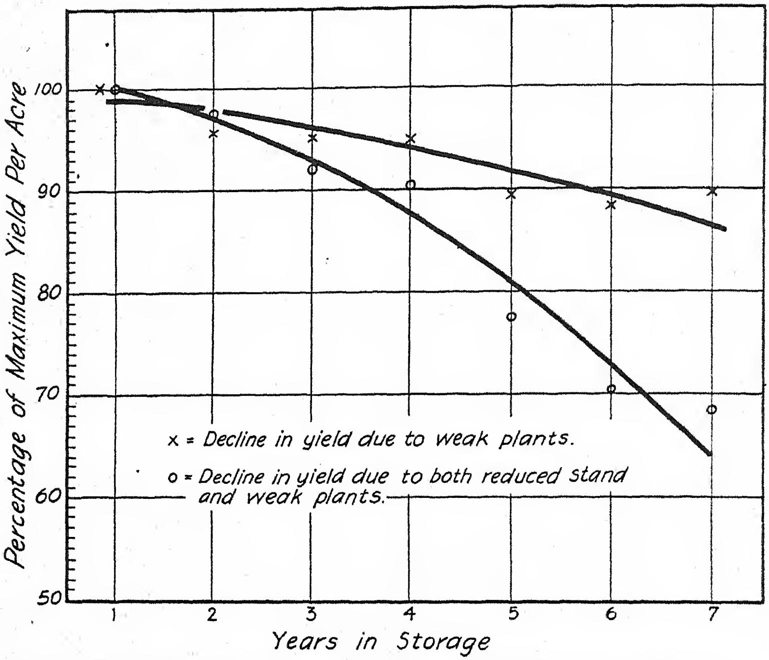


FIG. 3.—Weak plants as a factor in reduced yields from old seed corn.

SUMMARY

Aging markedly reduced the prevalence of viable fungi in infected seed corn. *Gibberella zeae* infection was almost completely eliminated in seed corn held over 1 year. During the same time *Nigrospora oryzae* infection was greatly reduced and *Diplodia zeae* was reduced about 50%. *Cephalosporium acremonium* and *Fusarium moniliforme* infections were reduced considerably after 3 years, but some traces of them remained up to 7 and 8 years of storage.

Decrease in yield from old seed corn was caused by a reduction in field stand and also to a less extent by a lowered yield per plant. Three-year-old seed of six lots of corn averaged 4.8% lower in yield than 1-year-old seed when both lots had a perfect stand. When reduced stand also was allowed to influence the yield the 3-year-old seed yielded 7.8% under 1-year-old seed. With high quality seed originally, yields declined gradually, but fair yields were obtained for 6 years. With corn of average commercial quality, yields from 2- and 3-year-old seed were found to be significantly lower than yields from seed of the previous season's crop.

LITERATURE CITED

1. DUNGAN, GEORGE H. Influence of age on the value of seed corn. Trans. Ill. State Acad. Sci., 33:28–29. 1940.
2. KIESSELBACH, T. A. Effect of age, size, and source of seed on the corn crop. Nebr. Agr. Exp. Sta. Bul. 305:1–16. 1937.

3. Koehler, Benjamin, and Holbert, J. R. Corn diseases in Illinois, their extent, nature, and control. Ill. Agr. Exp. Sta. Bul. 354. 1930.
4. Robertson, D. W., Lute, A. M., and Kroeger, H. Germination of 20-year-old wheat, oats, barley, corn, rye, sorghums, and soybeans. Jour. Amer. Soc. Agron., 35:786-795. 1943.
5. Shands, R. G. Longevity of *Gibberella saubinetii* and other fungi in barley kernels and its relation to the emetic effect. Phytopath., 27:749–762. 1937.

BARLEY VARIETIES REGISTERED, IX[1]

H. K. Hayes[2]

FIFTEEN varieties of barley have been registered and described in eight previous reports, the last report appearing in this Journal in 1943.[3] An additional variety, named Glacier, has been approved for registration.

GLACIER, REG. No. 16

This variety is a selection from a cross of Atlas × Vaughn made by V. H. Florell in 1927 at Davis, Calif., and selected in the F_5 generation by him at Moscow, Idaho. It was first tested in 1935 at Moccasin, Mont., and was developed cooperatively and first distributed in 1943 in Montana by the Montana Agricultural Experiment Station and the U. S. Dept. of Agriculture. It is a six-rowed, white-seeded, hulled, semi-smooth awned, and produces mostly erect, dense spikes. It has high yielding ability, stiff straw, and is highly resistant to covered smut.

Comparative yields of Glacier and Trebi, a standard variety, in bushels per acre are given in Table 1 at two dryland stations, Moccasin and Havre, Mont., and under irrigated conditions at Bozeman, Mont. The nursery plots at each of the three stations and the 1/56-acre field plots at Bozeman were replicated three times, while the 1/50-acre field plots at Moccasin and Havre were in quadruplicate.

Table 1.—*Comparative grain yields in bushels per acre of Glacier and Trebi in nursery and field plot trials at Bozeman, Moccasin, and Havre, Mont.*

Variety	C.I. No.	Nursery					Field plots		Average
		1936	1937	1938	1939	1940	1941	1942	
Irrigated, Bozeman									
Glacier (New)....	6,976	—	120.7	94.0	100.7	94.1	116.7	90.4	102.8
Trebi (Standard)	936	—	76.2	68.2	46.0	74.9	95.7	91.4	75.4
Dryland, Moccasin									
Glacier (New)....	6,976	17.0	8.2	43.2	23.4	19.4	44.8	—	26.0
Trebi (Standard)	936	9.4	5.5	43.6	22.5	13.3	34.5	—	21.5
Dryland, Havre									
Glacier (New)....	6,976	—	—	—	—	39.1	49.7	47.9	45.6
Trebi (Standard)	936	—	—	—	—	23.6	32.3	36.8	30.9

[1]Registered under a cooperative agreement between the Bureau of Plant Industry, Soils, and Agricultural Engineering, U. S. Dept. of Agriculture, and the American Society of Agronomy. Received for publication January 18, 1944.

[2]Chief, Division of Agronomy and Plant Genetics, Department of Agriculture, University of Minnesota, St. Paul, Minn. Member of committee on Varietal Standardization and Registration of the Society charged with the registration of barley varieties.

[3]Hayes, H. K. Barley varieties registered, VIII. Jour. Amer. Soc. Agron., 35:240. 1943.

REGISTRATION OF VARIETIES AND STRAINS OF OATS, XIII[1]

T. R. Stanton[2]

THE twelfth consecutive report (3)[3] on the registration of improved oat varieties was published in March 1943. During the past year one additional variety, described below, was submitted and approved for registration.

Group and Varietal Name	Reg. No.
Early yellow:	
Cedar	103

Cedar (C.I.[4] 3314) (Plant Sel. 5545–522) originated from the same cross, Victoria × Richland, from which the previously registered varieties Boone, Vicland, and Tama were derived (3). This cross was made in the greenhouse at the Arlington Experiment Farm, Arlington, Va., in 1930. The history of Cedar thus is similar to that of the selections comprising the above-mentioned varieties (3,4,5).

Seed of selection C. I. 3314 and three sibs were sent from Ames, Iowa, by L. C. Burnett to Lincoln, Nebr., where these selections were tested in replicated field plots from 1938 to 1943, inclusive.

The selection C. I. 3314 proved to be outstanding for yield and quality and was named Cedar in 1943 (1). Cedar thus was developed and named cooperatively by the Iowa and Nebraska experiment stations and the Bureau of Plant Industry, Soils, and Agricultural Engineering, U. S. Dept. of Agriculture. The application for the registration of cedar was submitted by H. C. Murphy and K. S. Quisenberry.

About 150 bushels of Cedar oats were distributed to certified growers in Nebraska in the spring of 1943. The variety will be distributed in 1944 to farmers chiefly in the east-central and northeastern parts of that state (1).

Cedar, like its sister varieties, is an early yellow common oat with short, stiff straw. Its superior characters are early maturity, high yield and quality, and satisfactory resistance to nearly all physiologic races of the oat rusts and smuts (2). It has been grown in extensive nursery tests at Ames and Kanawha, Iowa, for 6 and 4 years, respectively, and in replicated drill plots at Lincoln and Alliance, Nebr., for 6 and 4 years, respectively, in comparison with standard varieties. The yield data thus obtained are given in Table 1.

In acre yield, Cedar has been slightly superior to Tama in Iowa and decidedly superior to the old Kherson oat in Nebraska. Like

[1]Registered under cooperative agreement between the Bureau of Plant Industry, Soils, and Agricultural Engineering, Agricultural Research Administration, U. S. Dept. of Agriculture, and the American Society of Agronomy. Received for publication January 19, 1944.

[2]Senior Agronomist, Division of Cereal Crops and Diseases, Bureau of Plant Industry, Soils, and Agricultural Engineering, member of the 1943 committee on Varietal Standardization and Registration charged with the registration of oat varieties.

[3]Reference by number is to "Literature Cited", p. 446.

[4]C.I. refers to accession number of the Division of Cereal Crops and Diseases.

TABLE 1.—*Yields of Cedar and other oat varieties in Iowa and Nebraska.**

Variety	C. I. No.	Acre yield, bushels						
		1938	1939	1940	1941	1942	1943	Av.
Ames, Iowa								
Cedar	3314	73.1	50.0	85.3	—	77.5	77.1	72.6
Tama	3502	65.6	55.6	85.3	—	74.1	74.9	71.1
Boone	3305	70.6	44.7	83.1	—	67.5	68.2	66.8
Marion	3247	46.6	54.1	84.8	—	67.0	64.1	63.3
Gopher	2027	44.2	55.0	81.9	—	80.9	58.0	64.0
Kanawha, Iowa								
Cedar	3314	—	—	73.1	48.9	68.5	75.1	66.4
Tama	3502	—	—	71.0	46.0	65.8	70.8	63.4
Boone	3305	—	—	71.0	51.6	55.3	60.1	59.5
Marion	3247	—	—	68.9	53.8	69.5	67.9	65.0
Gopher	2027	—	—	63.4	11.6	63.3	37.9	44.1
Lincoln, Nebr.								
Cedar	3314	73.9	28.2	22.8	68.3	72.7	84.4	58.4
Otoe	2886	68.6	26.5	24.0	60.8	67.7	66.8	52.4
Kherson	1209	54.6	26.1	19.6	47.3	56.9	65.1	44.9
Alliance, Nebr.								
Cedar	3314	—	—	7.2	81.4	40.8	—	43.1
Otoe	2886	—	—	9.7	59.6	36.2	—	35.2
Kherson	1209	—	—	5.8	74.3	33.6	—	37.9

*Nurseries at Ames and Alliance destroyed by hail in 1941 and 1943, respectively.

Tama and Control, Cedar has been less susceptible than Boone to leaf spot in Iowa. For additional yield data on Cedar and similar varieties see reports by Burnett and Murphy[5] and by Coffman.[6]

LITERATURE CITED

1. KEIM, F. D. New crop varieties for Nebraska. Oat—A new oat named Cedar will be available this spring. Nebr. Farmer, 85 (No. 6): 1; 2. 1943.
2. MURPHY, H. C., STANTON, T. R., and COFFMAN, F. A. Breeding for disease resistance in oats. Jour. Amer. Soc. Agron., 34:72-89. 1942.
3. STANTON, T. R. Registration of varieties and strains of oats, IX, X, XI, and XII. Jour. Amer. Soc. Agron., 32:76–82, 1940; 33:246–251. 1941; 34:275–279. 1942; and 35:242–244, 1943.
4. ————, MURPHY, H. C., COFFMAN, F. A., BURNETT, L. C., and HUMPHREY, H. B. New disease-resistance early oats from a Victoria-Richland cross. Jour. Amer. Soc. Agron., 30:998–1009. 1938.
5. ———— and COFFMAN, F. A. Grow disease-resistant oats. U. S. Dept. Agr. F. Bul. 1941. Pp. 13. 1943.

[5]BURNETT, L. C., and MURPHY, H. C. Small grain. Information from experiments in progress. Iowa Agr. Exp. Sta. and Ext. Service Leaflet F. C. 17. 16 pp. [Mimeographed.] 1943.

[6]COFFMAN, F. A. Results from the cooperative coordinated oat breeding nurseries for 1942 and the uniform winterhardiness nurseries, 1942–43, U. S. Dept. Agr., Agr. Res. Adm., Bur. Plant Indus., Soils, and Agr. Engin., Div. Cereal Crops and Dis. [Unnumb. Pub.] 69 pp. June 1943. [Processed.]

REGISTRATION OF IMPROVED WHEAT VARIETIES, XVI[1]

J. ALLEN CLARK[2]

FIFTEEN previous reports present the registration of 66 improved varieties of wheat. In 1942 two varieties were registered.[3] Four varieties have been approved for registration in 1943. These are:

Class and Varietal Name	*Reg. No.*
Soft Red Winter:	
Fairfield	332
Durum:	
Carleton	333
Stewart	334
Hard Red Spring:	
Newthatch	335

FAIRFIELD (REG. No. 332)

Fairfield (Purdue No. 6, C.I.[4] 12013) was developed by the Agronomy Department of the Purdue Agricultural Experiment Station from a cross between the Purkof and Fulhio varieties made in 1926. The strain resulting in Fairfield was last selected in 1932. Yield and other results from the Soils and Crops Experiment Farm, Lafayette, Ind., for the 9 years, 1933 to 1941, for 6 years at the Wagner farm Chandler, Ind., and for 2 years at seven locations in the State are available.

These data[5] indicate that Fairfield excels with regard to yield and resistance to cold and winterkilling and to loose smut and mosaic. Special attention has been given to quality throughout the period of selection and testing. Three tests, *viz.*, (1) the fermentation time test, (2) the granulation test for flour particle size, and (3) the photoelectric cell test for yellow pigment were made in Indiana. Experimental milling and baking tests were made by the Federal Soft Wheat Laboratory, Wooster, Ohio, and by two large commercial mills in Indiana, with satisfactory results. Fairfield was distributed for commercial production in the fall of 1942.

CARLETON, REG. No. 333

Carleton (Ld. 104, C.I. 12064) was developed in cooperative experiments by the North Dakota Agricultural Experiment Station

[1]Registered under a cooperative agreement between the Bureau of Plant Industry, Soils, and Agricultural Engineering, Agricultural Research Administration, U. S. Dept. of Agriculture, and the American Society of Agronomy. Received for publication January 19, 1944.

[2]Senior Agronomist, Division of Cereal Crops and Diseases, U. S. Dept. of Agriculture. Member of the 1943 committee on Varietal Standardization and Registration of the Society charged with the registration of wheat varieties.

[3]CLARK, J. ALLEN. Registration of improved wheat varieties, XV. Jour. Amer. Soc. Agron., 35:245–248. 1943.

[4]C.I. refers to accession number of the Division of Cereal Crops and Diseases.

[5]CUTLER, G. H. Fairfield wheat. Purdue Univ. Agr. Exp. Sta. Circ. 276. 1942.

and the Division of Cereal Crops and Diseases, Bureau of Plant Industry, Soils, and Agricultural Engineering, U. S. Dept. of Agriculture. The North Dakota, Minnesota, South Dakota and Manitoba agricultural experiment stations cooperated in testing it in comparison with other varieties.

Carleton is a result of a program of backcrossing Vernal emmer to Mindum durum wheat, the object being to produce a high quality durum wheat carrying the stem-rust resistance of the emmer. The first cross, Vernal × Mindum, was made in 1930. A selected F_3 progeny was crossed to Mindum in 1932, giving a first backcross hybrid. A selected F_4 progeny from this backcross was again crossed to Mindum in 1936, giving a second backcross hybrid. An F_4 row from this second backcross was selected in 1938 and increased as Ld. 104 to become Carleton.

Carleton is distinctly superior to Mindum or Kubanka in stem-rust resistance and in strength of straw. It is not usually superior to Mindum in yield, except in stem rust years. Stem rust in the field plots has not been heavy enough in recent years to damage Mindum severely. However, in 1941 nursery rows at Langdon, stem rust averaged 60% on Mindum and 3% on Carleton, giving Carleton an advantage of 4 to 6 pounds in test weight and 25% in yield. Carleton makes its strongest appeal to growers by its growth habit, standing up rather erect in contrast to the usual nodding head type of Mindum and Kubanka. The straw is heavy and coarse, a factor which may possibly reduce its yield of grain in some cases. Under conditions of severe lodging in 1942 and 1943, Carleton in all nurseries, field plots, and farm increase fields that were observed showed considerably more resistance to lodging than Mindum, although there were fields where Carleton also was lodged. Extensive macaroni quality tests indicate Carleton is equal to Mindum in macaroni quality. Yearly averages of macaroni color scores of Carleton, Stewart, and Mindum are given in Table 1.

TABLE 1.—*Macaroni color score of Carleton, Stewart, and Mindum wheats.*

Crop year	No. of samples	Average macaroni color score*		
		Carleton	Stewart	Mindum
1939	2	75.0	70.0	72.5
1940	4	65.0	61.7	66.2
1941	6	68.8	72.1	67.9
1942	4	75.6	68.1	70.0
Weighted 4-year av.		70.3	68.6	68.6

*Samples processed by General Mills and scored without operator knowing identity of sample.

The annual and average plot yields of Carleton in comparison with those of Mindum and Stewart at Langdon and other cooperating stations are shown in Table 2. Carleton was released for distribution in 1943.

STEWART, REG. No. 334

Stewart (Ld. 111, C.I. 12066) was developed in cooperative experiments by the Division of Cereal Crops and Diseases, Bureau of Plant Industry, Soils, and Agricultural Engineering, U. S. Department of Agriculture, and the North Dakota Agricultural Experiment Station. It is a product of the same backcrossing program which produced Carleton. Stewart resulted from a selected progeny of Mindum × Vernal emmer backcrossed to Mindum. A selected F_4 progeny of the

TABLE 2.—*Annual and average yields in field plots of Carleton, Stewart, and Mindum wheats at Langdon, N. Dak., and other cooperating stations, and test weights at Langdon.*

Variety	Yield in bu. per acre					Percentage of Mindum
	1940	1941	1942	1943	Average	
			Langdon, N. Dak.			
Stewart	26.8	36.9	39.4	45.9	37.2	103.0
Mindum	25.1	34.9	39.1	45.4	36.1	100.0
Carleton	25.9	37.2	34.4	40.8	34.6	95.9
			Fargo, N. Dak.			
Mindum	15.1	27.9	54.3	20.3	29.4	100.0
Stewart	15.1	26.6	54.1	19.8	28.9	98.3
Carleton	14.9	23.9	47.3	16.4	25.6	87.1
			St. Paul, Minn.			
Mindum	—	27.5	43.0	30.3	33.6	100.0
Stewart	—	24.3	42.7	29.9	32.3	96.1
Carleton	—	19.0	40.8	23.7	27.8	82.7
			Crookston, Minn.			
Carleton	—	30.7	33.7	37.1	33.8	100.6
Mindum	—	30.4	35.1	35.4	33.6	100.0
Stewart	—	36.3	26.9	35.7	33.0	98.2
			Morris, Minn.			
Stewart	—	—	—	27.4	27.4	110.5
Mindum	—	—	—	24.8	24.8	100.0
Carleton	—	—	—	24.7	24.7	99.6
			Brookings, S. Dak.			
Stewart	—	—	—	24.5	24.5	124.4
Mindum	—	—	—	19.7	19.7	100.0
Carleton	—	—	—	16.1	16.1	81.7
			Av. Six Stations, 16 Tests			
Stewart	21.0	31.0	40.8	30.5	32.0	100.6
Mindum	20.1	30.2	42.9	29.3	31.8	100.0
Carleton	20.4	27.7	39.1	26.5	29.2	91.8
			Test Weights at Langdon, N. Dak.			
Carleton	64.0	60.0	62.0	64.0	62.5	100.6
Stewart	63.0	59.8	62.0	64.5	62.3	100.3
Mindum	63.5	58.5	62.0	64.5	62.1	100.0

first cross was crossed to Mindum in 1933, giving the first backcrossed hybrid. A selected F_4 progeny of this backcross was again crossed to Mindum in 1936 and an F_4 row from this second backcross progeny was selected in 1938 and increased as Ld. 111 and later named Stewart.

Stewart is superior to Mindum or Kubanka in stem-rust resistance, being resistant to the prevailing races of stem rust. It is equal to Mindum in yield, test weight, and macaroni quality, and is similar to Mindum in strength of straw. Stewart is slightly more difficult to thresh and less likely to shatter, a characteristic obtained from the emmer parent.

Although inferior to Carleton in strength of straw, Stewart appeals to many growers because it has been rather consistently higher in

TABLE 3.—*Agronomic, disease, and quality data on Newthatch and Thatcher grown in nursery and field plot experiments at the four stations, University Farm, Waseca, Morris, and Crookston, Minn., 1939–43.*

Experiment and variety	1939	1940	1941	1942	1943	Average	Percentage of Thatcher
			Yield Per Acre, Bu.				
Nursery:							
Newthatch	21.8	33.6	24.0	30.0	—	27.4	122
Thatcher	18.9	30.6	14.7	25.2	—	22.4	100
			Stem Rust Infection (St. Paul Rust Nursery), %				
Newthatch	Trace	Trace	Trace	Trace	Trace	Trace	
Thatcher	5	10	Trace	Trace	Trace	3	
			Leaf Rust Infection (St. Paul Rust Nursery), %				
Newthatch	14	8	Trace	Trace	Trace	4	
Thatcher	80	80	60	80	60	72	
			Weight Per Bushel, Lbs.				
Newthatch	55.8	57.8	55.1	59.0	—	56.9	100
Thatcher	57.5	57.6	54.5	57.9	—	56.9	100
			Yield Per Acre, Bu.				
Plots:							
Newthatch	—	—	30.8	39.2	28.0	32.7	131
Thatcher	—	—	18.9	30.0	26.2	25.0	100
			Weight Per Bushel, Lbs.				
Newthatch	—	—	54.8	58.7	55.3	56.3	102
Thatcher	—	—	51.8	57.8	56.4	55.3	100
			Protein, %				
Nursery and Plots:							
Newthatch	17.1	16.9	15.4	14.1	—	15.9	110
Thatcher	14.9	15.8	13.7	13.5	—	14.5	100
			Loaf Volume, cc				
Newthatch	797	857	795	817	—	815	100
Thatcher	851	851	785	757	—	811	100

yield. The annual and average plot yields of Stewart in comparison with Mindum and Carleton at Langdon and other cooperating stations are shown in Table 2.

Stewart was released for distribution in 1943. For further information on Carleton and Stewart durum wheats, see Smith.[6]

NEWTHATCH

Newthatch (Minn. 2652, C.I. 12318) was developed in cooperative experiments of the Minnesota Agricultural Experiment Station and the Division of Cereal Crops and Diseases, Bureau of Plant Industry, Soils, and Agricultural Engineering, U. S. Dept. of Agriculture. It was produced by backcrossing in which Thatcher was used as the

TABLE 4.—*Annual and average yields of Newthatch in comparison with the four leading spring wheat varieties at four Minnesota experiment stations for the years 1941–43.*

Variety	1941	1942	1943	Average	Percentage of Thatcher
			St. Paul		
Newthatch	33.2	43.5	28.4	35.0	146.4
Pilot	32.8	39.4	28.8	33.7	141.0
Rival	30.9	33.3	29.5	31.2	130.5
Regent	26.4	34.5	23.7	28.2	118.0
Thatcher	19.1	26.2	26.4	23.9	100.0
			Waseca		
Newthatch	26.4	30.1	19.0	25.2	130.6
Pilot	29.6	31.6	23.9	28.4	147.2
Rival	28.5	26.3	19.6	24.8	128.5
Regent	24.7	28.6	17.8	23.7	122.8
Thatcher	16.2	23.3	18.3	19.3	100.0
			Morris		
Newthatch	30.0	42.4	26.9	33.1	118.6
Pilot	30.4	47.2	26.8	34.8	124.7
Rival	28.5	48.8	26.3	34.5	123.7
Regent	24.7	44.1	23.8	30.9	110.8
Thatcher	18.4	39.3	26.1	27.9	100.0
			Crookston		
Newthatch	33.3	40.7	37.6	37.2	128.3
Pilot	28.8	42.6	33.4	34.9	120.3
Rival	26.6	38.4	37.5	34.2	117.9
Regent	30.6	38.5	35.2	34.8	120.0
Thatcher	21.8	31.2	34.1	29.0	100.0
			Average for Four Minnesota Stations		
Newthatch	30.7	39.2	28.0	32.6	130.4
Pilot	30.4	40.2	28.2	32.9	131.6
Rival	28.6	36.7	28.2	31.2	124.8
Regent	26.6	35.9	25.1	29.2	116.8
Thatcher	18.9	30.0	26.2	25.0	100.0

[6]SMITH, GLENN S. Two new durum wheat varieties. N. Dak. Agr. Exp. Sta. Bimo. Bul., 5: No. 4, 2–5. 1943.

recurring parent and Hope as the nonrecurring parent. The original cross made at the Minnesota Agricultural Experiment Station in 1930 and two backcrosses to Thatcher were carried out under the direction of Dr. E. R. Ausemus. Subsequent selection was made for leaf- and stem-rust resistance. Newthatch is made up of eight Hope × Thatcher[7] backcross strains, all of which trace back to a single F_2 plant from the second backcross.

Newthatch is a spring wheat with glabrous, white glumes, awnless and hard red kernels. It is very similar to Thatcher in plant and kernel type but superior to Thatcher in yield and leaf- and stem-rust resistance. It is very resistant to lodging and has excellent milling and baking qualities.

Newthatch has been equal to or superior to Thatcher in all other important characteristics in trials at the four Minnesota stations, University Farm, Waseca, Morris, and Crookston, during the 4-year period, 1939–42. Data on certain of the more important characters in comparison with Thatcher are given in Table 3, and the annual and average yields of Newthatch, Thatcher, Pilot, Rival, and Regent, the leading commercial varieties, at each of the stations, in Table 4. Approximately 1,500 bushels of seed were produced at the Minnesota experiment stations in 1943. It is planned to release the variety to farmers in the spring of 1944.

[7]See footnote 3.

REGISTRATION OF SORGHUM VARIETIES, IV[1]

R. E. Karper[2]

ONE improved variety of sorghum was approved for registration in 1943 under the name of Westland, Reg. No. 80.

Westland is a combine-type grain sorghum originating from selection made from Wheatland in 1930 by F. A. Wagner, formerly Superintendent of the Garden City Branch of the Kansas Experiment Station. The original selection was only partially resistant to Pythium root rot when grown in 1931. After several years of growing on disease-infested soil, selecting resistant plants, a selection was obtained which is pure for resistance to this disease. The original selection was probably the result of a natural cross between Wheatland and some other yellow-seeded milo type hybrid since it was still segregating for several characters more typical of other milo hybrids when taken over by Alvin E. Lowe in 1937. The selection, after adequate purification and testing was named Westland in February, 1941, and an increase field of 35 acres was grown the same year. Seed was released to farmers in the spring of 1942.

Westland is a double dwarf variety with a stalk and head resembling kafir. It is about 3 inches taller than Wheatland as it has a longer peduncle and exserts further out of the boot, placing the head well above the upper leaves. The seed of Westland are similar in size and shape to those of kafir but are a brighter yellow in color than the seed of Wheatland. The glumes are black. Westland is an early maturing variety producing relatively few tillers which are of uniform height with the main plants. The stalks of Westland are short and sturdy and are resistant to lodging. This new variety is resistant to milo root rot, enabling it to produce a good crop on disease-infested soil where Wheatland and other susceptible varieties fail. Table 1 gives the yield of Westland and other varieties grown at Garden City, Kans., 1939–41, inclusive.

Table 1.—*Yields in bushels per acre of Westland and other varieties of sorghum tested at Garden City, Kans., 1939–41, inclusive.*

Varieties	1939	1940	1941	Average
Westland	9.5	10.4	49.0	23.0
Wheatland	8.4	7.0	34.5	16.6
Finney	8.0	0.4	50.3	19.6
Colby	9.7	7.5	31.6	16.3

[1]Registered under cooperative agreement between the Bureau of Plant Industry, Soils, and Agricultural Engineering, Agricultural Research Administration, U. S. Dept. of Agriculture, and the American Society of Agronomy. Received for publication January 18, 1944.

[2]Agronomist in Charge of Sorghum Investigations, Texas Agricultural Experiment Station, College Station, Texas. Member of the committee on Varietal Standardization and Registration of the Society charged with the registration of sorghum varieties.

REGISTRATION OF IMPROVED FLAX VARIETIES, II[1]

A. C. ARNY[2]

THE first report on registration of improved varieties of flax was published in the September, 1943, issue of the JOURNAL. Two registered varieties were described in that Report.

CRYSTAL REG. No. 3

Crystal is a selection from the cross Bison × 770B made at University Farm, St. Paul, Minn., in 1930. When the cross was made, the aim was to combine in new varieties the vigorous plant type, the high yielding ability, and the high percentage of oil in the seed of the Bison parent together with the moderately high oil quality and immunity to flax rust, *Melampsora lini*, of the 770B parent. Crystal is the result of cooperative effort between the Minnesota Experiment Station and the U. S. Dept. of Agriculture.

The 770B parent was not included in the tests to determine the value of Crystal. Data for Redwing have been included in the tables for comparison since it has been a high-yielding variety and has produced high-quality oil. The yields are reported in Table 1.

TABLE 1.—*Yields in bushels per acre of Crystal compared with those of Redwing and Bison at Minnesota stations.*

Variety	C.I. No.	St. Paul, 1939–40	Waseca, 1939–40	Morris, 1940	Crookston, 1940	Av.
State Rod-row Tests						
Redwing	320	22.1	22.6	15.9	15.9	20.2
Bison	389	15.9	22.4	17.6	16.7	18.5
Crystal	982	17.1	24.1	18.9	18.4	20.2
Sig. dif. at 5% point		3.5	3.6	3.0	4.2	1.8
1/40-Acre Plot Tests						
Variety	C.I. No.	1941–42	1941–42	1941–42	1942	Av.
Redwing	320	17.2	24.4	19.7	6.7	18.4
Bison	389	13.3	20.6	19.1	9.5	16.5
Crystal	982	8.5	24.4	22.5	16.2	18.1
Sig. dif. at 5% point		4.0	2.0	2.5	3.0	1.5

[1]Registered under cooperative agreement between the Bureau of Plant Industry, Soils and Agricultural Engineering, Agricultural Research Administration, U. S. Dept. of Agriculture, and the American Society of Agronomy. Received for publication January 19, 1944.

[2]Associate Agronomist, Division of Agronomy and Plant Genetics, Dept. of Agriculture, Forestry and Home Economics, University of Minnesota, St. Paul, Minn. Member of committee on Varietal Standardization and Registration of the Society charged with the registration of flax varieties.

In the rod-row tests, the yields of Crystal, with one exception, were somewhat higher, but not significantly so, than those for Bison and Redwing. The average yield of Crystal in these tests was 1.7 bushels higher than that of Bison. In the 1/40-acre plot tests, the average yields of Crystal at Morris and Crookston were significantly higher than those for Bison and Redwing. This advantage of Crystal was due largely to its immunity to rust. The average yield for Crystal was significantly higher than the yield for Bison. The significantly low average yield of Crystal at St. Paul was due to loss of stand from a form of wilt not common in the Northwest.

The data given in Table 2 show that over the 4-year period Crystal grew from an inch to 2 inches taller and tended to mature a day or two later than Bison. The weight of 1,000 seeds and the oil content of Crystal were similar to those for Bison. Crystal produced oil distinctly higher in drying quality than that of Bison and approaching fairly closely to that of Redwing.

TABLE 2.—*Agronomic data, other than yield, and chemical data for Crystal compared with those for Redwing and Bison at Minnesota stations.*

Variety	C.I. No.	Height, in.	Date mature	1,000 seeds, grams	Oil, %	Iodine No. of oil
Averages for State Rod-row Tests, 1939–40						
Redwing.......	320	24	July 29	4.3	35.1	183
Bison..........	389	25	Aug. 1	5.0	35.9	172
Crystal........	982	26	Aug. 1	5.6	36.1	182
Averages for 1/40-acre Plot Tests, 1941–42						
Redwing.......	320	25	July 30	4.5	36.0	186
Bison..........	389	26	Aug. 2	5.8	37.6	175
Crystal........	982	28	Aug. 4	5.6	36.4	182

Crystal has white flowers with comparatively narrow crimped petals and yellow seeds with a greenish cast. These characters are useful in distinguishing it from other commercially grown varieties.

In addition to being immune to all North American races of flax rust, Crystal has shown immunity to two out of three Argentine

TABLE 3.—*Rust, wilt, and pasmo infection for flax varieties in the agronomy tests at four stations and in the Plant Pathology wilt nursery at St. Paul and Plant Pathology rust nursery at Anoka, Minn.*

Variety	C.I. No.	Rust infection*		Wilt percentage		Pasmo infection*	
		Av. of 3 tests, 1939–40	Av. of 6 tests, 1941–42	One test, 1939	Av. of 4 tests, 1941–42	Av. of 2 tests, 1939–40	Av. of 4 tests, 1941–42
Redwing	320	M–	M	40	24	M	L+
Bison...	389	M+	H	8	5	L+	L–
Crystal..	982	O	O	28	31	M–	L–

*H = heavy; M = moderate; L = light; O = none.

races for which it has been tested. In the Plant Pathology wilt nursery at St. Paul and in the majority of the field tests, Crystal and Redwing reacted similarly to wilt, *Fusarium lini*. Pasmo, *Phlyctaena linicola*, infection of Crystal and Bison was similar. Data on the susceptibility of Crystal and other varieties to disease are given in Table 3.

ROYAL, REG. No. 4

Royal (Sask. 1727; C.I. 828) is a high-yielding variety selected for wilt resistance from the variety Crown by Dr. J. B. Harrington at the University of Saskatchewan at Saskatoon. The original selections, of which Royal proved the best, were made in 1927 from a continuous flax plot on which 99% of the plants of Crown had succumbed to wilt. Royal was first distributed to the public in small lots in 1938. In 1942 its estimated production was 225,000 bushels. The estimated area of Royal in Western Canada in 1943 was 400,000 acres.

Royal is a vigorous-growing variety, medium in plant height, with mid-sized blue blossoms and mid-sized brown seeds with characteristic whitish tips. It has good bushel weight. Royal is not quite as strong strawed as Bison, is a day or two later being mid-season in maturity, and does not rank as high in resistance to wilt. However, in the flax wilt nursery at Saskatoon in replicated yield tests from 1939 to 1942, Royal averaged 17.3 bushels per acre compared with 15.6 bushels for Bison and 11.7 bushels for Redwing. The necessary difference at the 5% point was 1.5 bushels. Royal has high mature plant resistance to rust. Saskatchewan results show it to have higher resistance to spring frost injury than Bison.

The summarized data in Table 4 show that Royal has significantly excelled both Bison and Redwing, the other commercial varieties of Saskatchewan, in yield over the past 10 years at Saskatoon. The average has been about 17% higher. In the U. S. Dept. of Agriculture Regional Flax Test at Saskatoon, Royal outyielded all the other varieties included in 1939. In 1940 and 1941 it was well up in yield in this test. At four Alberta stations, Royal outyielded Bison and Redwing during the period 1936 to 1942, inclusive. At the Federal Experiment Stations at Indian Head, Melfort, and Swift Current, Saskatchewan, Royal has averaged more than 15% above Bison

TABLE 4.—*Yields in bushels per acre of the leading flax varieties of western Canada at Saskatoon during the period 1932 to 1942.*

Variety	C.I. No.	Mean 1932–38	1939	1940	1941	1942	Means 1932–42	Means 1939–42
Royal	828	8.9	15.5	21.0	7.0	33.9	13.3	19.3
Bison	389	8.2	11.5	19.8	5.6	25.9	11.4	15.7
Redwing	320	8.0	11.5	18.3	5.1	26.3	11.1	15.3
Nec. diff. at 5% point		0.6	2.8	2.0	1.4	2.2	0.5	1.1

and Redwing over the past 5 years. Results on oil and iodine determinations are given in Table 5.

TABLE 5.—*Royal compared in oil percentages of the seed and oil quality with Bison and Redwing at Saskatoon.*

Variety	C.I. No.	1940 yield test		1941 and 1942 nursery test		1939–41 regional rod-row tests	
		Oil, %	Iodine No. of oil	Oil, %	Iodine No. of oil	Oil, %	Iodine No. of oil
Royal...	828	41.9	181	40.6	184	37.6	172
Bison...	389	41.7	183	40.7	178	37.3	173
Redwing	320	40.1	193	38.5	187	35.8	184

Royal resembles Bison in being high in oil percentage of the seed and only fair in oil quality as indicated by the iodine number.

REGISTRATION OF VARIETIES OF SOYBEANS, II[1]

W. J. Morse[2]

THE first report[3] on the registration of improved soybean varieties was published in September, 1943. Since that time three additional varieties, described in the following paragraphs, have been submitted and approved for registration.

PATOKA, REG. No. 2

Patoka is a pure-line selection from P.I. No. 70218–2[4] made at Patoka, Indiana, in 1934 by G. H. Cutler of the Purdue University Agricultural Experiment Station. P.I. No. 70218–2 originated from a selection made by W. J. Morse at Arlington Experimental Farm, Arlington, Virginia, in 1927, from P.I. No. 70218 received from Harbin, Manchuria, in 1926.

The Patoka makes an erect, somewhat bushy type of growth. It has purple flowers and gray pubescence and the foliage presents a typical grayish-green appearance. The pods are dark gray in color, medium to large in size, usually contain 2 to 3 seeds, and seldom shatter when ripe.

The seeds are medium to large (2,750 per pound) and straw yellow in color with a medium-sized black hilum which has a prominent white median line. On a moisture-free basis, seeds grown in southwestern Indiana contain 19.5 to 21% oil and 43 to 44% protein and the iodine number of the oil is 129 to 131.

In southern and southwestern Indiana where the Patoka is especially adapted, it ripens in 138 to 141 days when seeded at the normal planting time. Patoka has ripened satisfactorily as far north as Lafayette and its region of adaptation may be expected to extend well into the south central part of the state. Superior characters of the Patoka are high seed yield, high oil and high protein content, and suitability for combining.

The Patoka has been tested for 4 years at Lafayette and at four locations on different soil types in southwestern Indiana. Average (1938–41) yields, days to maturity, seeds per pound, and chemical analyses of the Patoka compared with other varieties and strains grown in southwestern Indiana are given in Table 1. For further

[1]Registered under a cooperative agreement between the Bureau of Plant Industry, Soils, and Agricultural Engineering, Agricultural Research Administration, U. S. Dept. of Agriculture, and the American Society of Agronomy. Received for publication January 19, 1944.

[2]Senior Agronomist, Division of Forage Crops and Diseases, Bureau of Plant Industry, Soils, and Agricultural Engineering, Agricultural Research Administration, U. S. Dept. of Agriculture. Member of the 1943 committee on Varietal Standardization and Registration. Charged with the registration of varieties of soybeans.

[3]Morse, W. J. Soybean variety registered. Jour. Amer. Soc. Agron., 35:834–835. 1943.

[4]P.I. refers to plant introduction number given by the Division of Plant Exploration and Introduction.

TABLE 1.—*Comparison of yield, days to maturity, seeds per pound, and chemical analyses of the seed of soybean varieties and strains grown in southwestern Indiana.**

Variety or strain	Average yield, bu. per acre, 1938–41	Average No. of days to maturity	No. of seeds per pound	Comparative chemical analyses (moisture-free basis)		
				Oil %	Protein %	Iodine No.
Kingwa	23.2	141	4,250	16.8	40.8	132.1
P.I. No. 54563-3	23.9	147	3,350	21.0	36.8	125.2
P. I. No. 70218-2	25.8	140	2,800	20.5	39.4	129.4
Macoupin	20.3	143	3,050	20.0	39.2	128.0
Patoka	26.6	140	2,750	20.1	43.9	130.4
Gibson	26.4	145	3,250	20.5	40.3	130.2

*These tests were conducted cooperatively between the U. S. Regional Soybean Laboratory and the Purdue Agricultural Experiment Station.

information on Patoka, see Purdue University Agricultural Experiment Station Circular 270.[5]

GIBSON, REG. No. 3

The Gibson is a selection (No. X 531-265-2-1-1-8) from a cross between Dunfield (female) and Midwest (male) made by G. H. Cutler at the Purdue University Agricultural Experiment Station, Lafayette, Ind., in 1930. This cross was made to combine the stiff stalk and growth characteristics of the Midwest with the good yield, high oil content, and superior seed qualities of the Dunfield. The last selection made from this cross was in 1936.

The Gibson is medium to tall in height with a semi-whip-like type of growth. It has white flowers and gray pubescence. The pods are light gray, medium-sized, contain 2 to 3 seeds, and the seed rarely shatter when ripe. The seeds are medium in size (3,250 per pound) and light creamy white with a colorless hilum. Moisture-free seed, when grown in southwestern Indiana, contain 20 to 21% oil, 40 to 41% protein and an oil iodine number of 129 to 131.

Gibson has been tested at Lafayette and at four locations on different soil types in southwestern Indiana. It ripens in about 145 days when seeded at the normal planting time and appears well adapted to southwestern Indiana. Although Gibson has ripened at Lafayette every year of its test, it would be on the average, if soybeans are followed by winter wheat, entirely too late for safe wheat seeding this far north. Average yields (1938-41), days to maturity, seeds per pound, and chemical analyses of the Gibson compared with other varieties and strains grown in southwestern Indiana are given in Table 1. For further information on Gibson, see Purdue University Agricultural Experiment Station Circular 270.[6]

[5] CUTLER, G. H., and PROBST, A. H. Gibson and Patoka soybeans. Purdue Univ. Agr. Exp. Sta. Circ. 270. 1942.

[6] *Loc. cit.*

EARLYANA, REG. No. 4

The Earlyana is a selection from the Dunfield variety made in 1931 by Claude Greenham of the Purdue University Agricultural Experiment Station, Lafayette, Ind. It seems probable that it originated from a natural hybrid.

The plant of the Earlyana has a semi-whip-like type of growth with the pods distributed somewhat sparsely along the main stem. The lower branches and pods are borne well off the ground. Earlyana has purple flowers and brown pubescence. The pods are brown, medium to large, containing two, three, and occasionally four seeds, and the seed seldom shatter when ripe. The seeds are medium-sized (2,750 per pound), light straw yellow with pale hilum and a brown speck at one end of the hilum. Moisture-free seeds contain 19.5 to 21% oil and 43 to 45% protein. The iodine number of the oil is 129 to 131. It has been observed that Earlyana grows relatively faster in the early stages of growth than other standard varieties with which it has been compared.

In quite extensive tests on different soil types in northern Indiana during the past 3 years Earlyana has ripened on the average 4 days earlier at Lafayette, 8 days earlier at Bluffton, and 11 days earlier at Wanatah than Richland. All tests indicate that Earlyana is adapted to a fairly wide range of soil and climatic conditions in north central and northern Indiana. In addition to being tested in Indiana, Earlyana has also been tested with eight commercial varieties in cooperation with the U. S. Regional Soybean Laboratory and the Illinois, Ohio, Iowa, and Missouri agricultural experiment stations. Even on soils of average fertility, Earlyana seems to have the ability of making a relatively tall growth. Seed of the Earlyana was made available for commercial production in 1943. It should serve a large portion of the soybean acreage throughout northern Indiana and areas of similar conditions where there is a demand for adapted early varieties. For further information on Earlyana, see Purdue University Agricultural Experiment Station Circular 286.[7]

Tests comparing yield and maturity of Earlyana and several other varieties of soybeans grown at several locations in north central and northern Indiana from 1940–42 are given in Table 2.

TABLE 2.—*Comparison of yield and maturity of several varieties of soybeans grown at different locations in north central and northern Indiana, 1940–42.**

Variety	Av. yield, bu. per acre				Maturity, days earlier (–) or later (+) than Richland			
	Lafayette	Bluffton	Wanatah	LaGrange†	Lafayette	Bluffton	Wanatah	LaGrange
Earlyana..	29.5	25.6	22.0	25.2	–4	–8	–11	–7
Richland..	30.0	26.4	20.3	22.4	0	0	0	0
Dunfield..	31.6	28.4	22.3	26.5	+8	+5	–1	+4
Mandell..	33.8	29.4	19.6	26.8	+10	+5	+3	+7

*These tests were conducted cooperatively between the U. S. Regional Soybean Laboratory and the Purdue Agricultural Experiment Station. †Data for LaGrange 1942 only.

[7]CUTLER, G. H., and PROBST, A. H. Earlyana—an early soybean for northern Indiana. Purdue Univ. Agr. Exp. Sta. Circ. 286. 1943.

NOTES

SAMPLING EAR CORN FOR MOISTURE DETERMINATION[1]

CORN yield trials require an adequate method of moisture determination if comparative yield and maturity values are to be accurately measured. Generally, moisture content of corn is determined by one of two methods, *viz.*, (1) from a sample of whole ears, or (2) from a sample of grain gouged from whole ears. Each of these methods has limitations. When tests involve large numbers of varieties, if method (1) is used, the amount of corn to be handled and the amount of space and time for drying become prohibitive; when method (2) is used, if the grain is of high moisture content, it is difficult with the general facilities at hand to make all moisture determinations before spoilage of the sample occurs.

Because hybrid corns being tested in different parts of Michigan vary from 25% to 60% in moisture content at harvest time and because of the limitations of the methods for determining moisture content now in general use, it became imperative that a new method be evolved for determining the moisture content of ear corn if Michigan trials were to be improved in accuracy. The requirements to be met by the new method were that the samples on which determinations were to be based should be (1) quickly and easily obtained, (2) representative of both grain and cob, (3) relatively small, (4) of such a character that they could be kept for 2 to 3 days under ordinary conditions without spoilage, and (5) easy to dry when placed in an oven.

In an attempt to develop a method to fulfill these requirements, a locally constructed device shown in Fig. 1 was used to remove a cross section from the ear of corn. It consists of a board base, 1 foot × 3 feet × 2 inches, in the center of which are bolted two pairs of mower section knives in such a position that a section 1 inch in width is sliced from the ear. The lever action handle is fixed to the frame so that pressure can be put on the ear that is placed crosswise of the knives, slicing out a section that drops through an opening in the board base. A removable funnel is fastened to the under side of the board base, guiding the sections into a paper bag. Three-pound paper bags punched with ¼-inch holes were used as containers for drying the sections in a hot air drier. The punched bag container allows free circulation of air which hastens drying considerably.

The routine use in sampling and testing our corn field plots for moisture is as follows: (1) A sample is taken from each plot harvested; (2) the sample is obtained by sectioning every third ear; (3) the sample is weighed immediately; (4) a large hot air oven is used to dry the samples; (5) a few samples are check-weighted at intervals until a constant weight is reached, usually 6 to 7 days; (6) all samples are reweighed as soon as a constant moisture is reached; and (7) the moisture content of several oven-dry samples (composite) is determined by the Brown-Duvel tester.

---

[1]Contribution from the Department of Farm Crops, Michigan Agricultural Experiment Station, East Lansing, Mich. Journal Article No. 699 (n.s.).

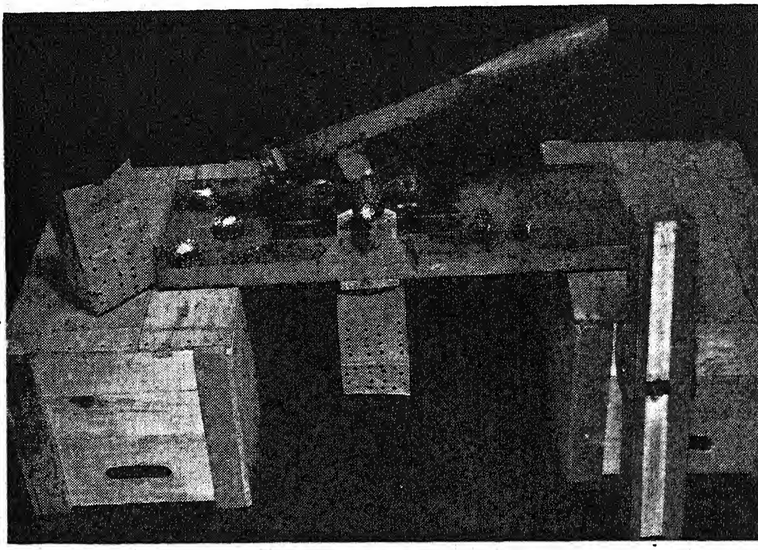


FIG. 1.—Device used to obtain samples from ears of corn for moisture content determinations.

The sectioning method was used throughout the 1943 corn harvest. It met Michigan's requirements for sampling ear corn to determine moisture content. Samples were taken, as shown in Table 1, to compare the moisture percentage as determined from whole ears, from kernels gouged from ears, and from cross sections of whole ears. Twenty samples of eight ears each were also taken on November 3 for the purpose of comparing the moisture content as determined from sections taken from the tip, middle, and butt portions of the ear. All samples were dried to constant weight in a forced hot-air oven and further tested in a Brown-Duvel moisture tester.

The moisture content of the sections (taken approximately midway between butt and tip) and of the gouged kernels were compared with the respective moisture contents of the whole ear from which they were removed, and the data are presented in Table 1.

TABLE 1.—*Moisture content as determined from whole ears, gouged kernels, and ear sections.*

Date of harvest	No. of samples	No. of ears per sample	Percentage moisture			
			Whole ears	Sections	Gouged kernels	Difference
Sept. 16.....	10	10	53.02	51.74	—	1.28**
16.....	10	10	52.22	—	49.30	2.92**
Nov. 3.....	20	8	36.07	35.71	—	0.36*
3.....	20	8	36.44	—	31.61	4.83**

*Significance at 5% level.
**Significance at 1% level.

On both dates of harvest, the moisture content as determined from sections more closely approximated the moisture content on the basis of whole ears than did the moisture content as determined from gouged kernels. The difference in moisture content as determined by sections and whole ears decreased as the corn approached maturity, whereas the differences between moisture content as determined by the gouging in comparison to the whole ears increased. This is explained by the fact that the cobs lag somewhat in drying-out in comparison to the kernels during the ripening period.

In comparing the moisture content of the sections cut from the tip, middle, and butt of 160 ears, the middle sections were slightly less in moisture than either of the two end sections. The tip, middle, and butt sections averaged 42.3, 41.1 and 43.1% moisture, respectively. These results compare favorably with those shown in Table 1, indicating that the middle portion of the ear is slightly lower in moisture than the two ends. However, in field operation, the sections can be taken at random, ranging from the tip to the butt, thus eliminating the slight difference in moisture existing in different longitudinal portions of the ear.—E. E. Down, J. W. Thayer, Jr., and E. Vander Meulen, *Department of Farm Crops, Michigan Agricultural Experiment Station, East Lansing, Mich.*

EFFECT OF MOISTURE, SEEDING DATES, AND FERTILIZER ON STANDS AND YIELDS OF CRIMSON CLOVER

CRIMSON clover (*Trifolium incarnatum* L.) is used in many sections of the southern United States as a winter annual legume because it is a heavy seed producer and adapted for pasture and green manure uses. Failure to obtain stands has limited the use of this legume. It is common practice in certain localities to plant the seed in the hull with the belief that better stands are obtained in this way. McKee[1] obtained good germination from seed that had swelled and then dried for several days, if the radicle had not appeared. Injury increased with length of drying time when the radicle was showing.

Studies were initiated at Statesville, N. C., during the period from 1935 to 1942 to investigate the effect of using hulled and unhulled seed, time of seeding, soil moisture, and phosphate fertilization upon germination and survival of crimson clover.

The rate of moisture absorption of hulled and unhulled seed was studied in the laboratory. Oven-dry Cecil sandy loam soil was brought up to 2, 5, 10, and 15% moisture levels. In each of the four lots of soil, 100-seed samples of hulled and of unhulled seed were placed between ½-inch layers of soil, the seed being protected from soil contamination by single thickness of paper toweling at the same moisture level as the soil. The seed tests in each moisture treatment were placed in metal containers, each treatment in triplicate, and an upper sample was removed for moisture test from each container at intervals of 2, 8, 12, 24, 36, and 48 hours.

The rate of moisture absorption from the soil in the laboratory is shown in Fig. 1. The hulled seed absorbed moisture more rapidly than the unhulled seed at all moisture levels. The rate of moisture absorption increased with the level of the soil moisture. Maximum moisture absorption was reached in 24 hours at the 2% and 5% levels and in 36 hours at the 10% and 15% levels. The radicles started to emerge in less than 24 hours at the 15% soil moisture level. At the 10% level radicles from hulled seed started to emerge in 36 hours. Emergence did not occur in the other samples at the 2%, 5%, and 10% moisture levels during the 48-hour period. Between 5% and 10% soil moisture was effective in causing radicle emergence in hulled seed and between 10% and 15% for unhulled seed. It is evident that more moisture is required for germination of unhulled than hulled seed.

In a second laboratory experiment, moisture absorption of hulled and unhulled seed and hulls were compared. Each individual lot of seed or hulls was placed on blotter paper saturated with water in Petri dishes. The lots of seed or hulls were in triplicate for each period of 2, 4, 6, 8, 10, 12, 24, and 36 hours. The rate of absorption, as shown in Fig. 2, was similar and quite rapid for 2 hours. This rapid rate of absorption continued in the hulled seed for 8 hours. The absorption

[1]McKEE, ROLAND. Vitality and germination of crimson clover seed as affected by swelling and sprouting and subsequent drying. Jour. Amer. Soc. Agron., 27:642–643. 1935.

rate of the unhulled seed and the hulls declined after 2 hours. The hulled seed absorbed about 47% more moisture in 36 hours than the hulls and 18% more than the unhulled seed. The hulls were effective in slowing down moisture absorption of crimson clover seed.

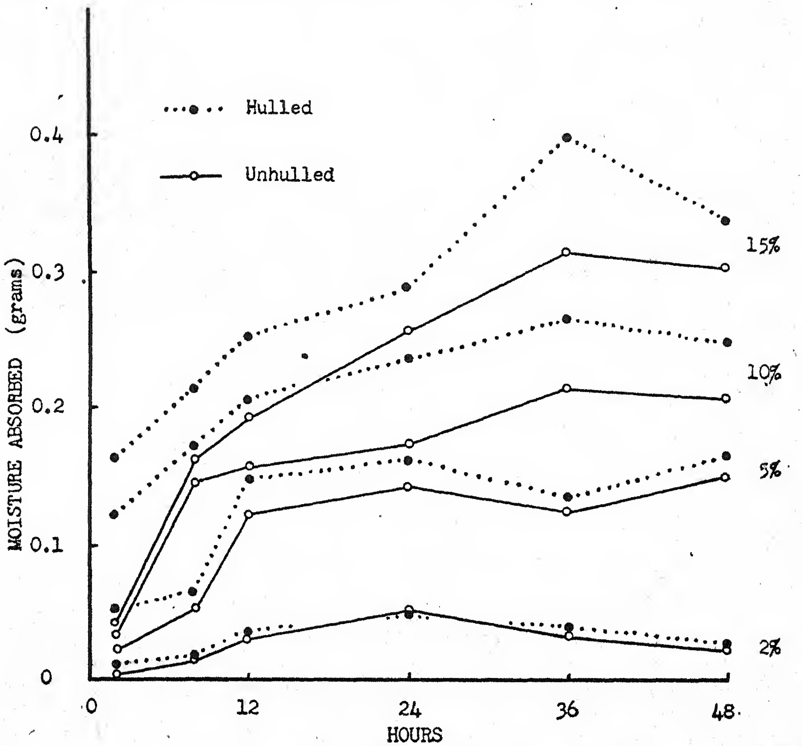


FIG. 1.—Moisture absorbed in grams per 100 seed by unhulled and hulled crimson clover seed at 2%, 5%, 10%, and 15% soil moisture.

Under field conditions mulched and bare plots were seeded to hulled and unhulled crimson clover on August 28. The mulch applied following seeding consisted of a ¼- to ½-inch layer of lespedeza leaves. The surface soil (½ inch deep) of the mulched plot contained 11.5% moisture and the bare plot 6.4%. The following day these plots contained 5.4% and 1.5% surface soil moisture, respectively. The moisture varied to a small extent during the next 2 days and it rained 1.67 inches on September 3, supplying adequate moisture for germination. The moisture level of the mulched plots on August 28 and 29 was high enough to cause emergence of the radicle, and subsequent drying resulted in stand reduction before the rain of September 3. On the mulched plots final stands were 35% on those seeded with unhulled seed and 10% with hulled seed, showing the protective function of the hull. On the bare plots the low moisture level from August 28 to September 2 prevented emergence of the

radicle and the rain of September 3 resulted in 70% stands with both hulled and unhulled seed.

The effectiveness of any given seeding date was found to be dependent upon time of season and precipitation. Seedings on North Carolina farms and experimental plots made later than October 1 under the climatic conditions at Statesville, N. C. were seldom successful due to winter injury and reduced growth in the spring.

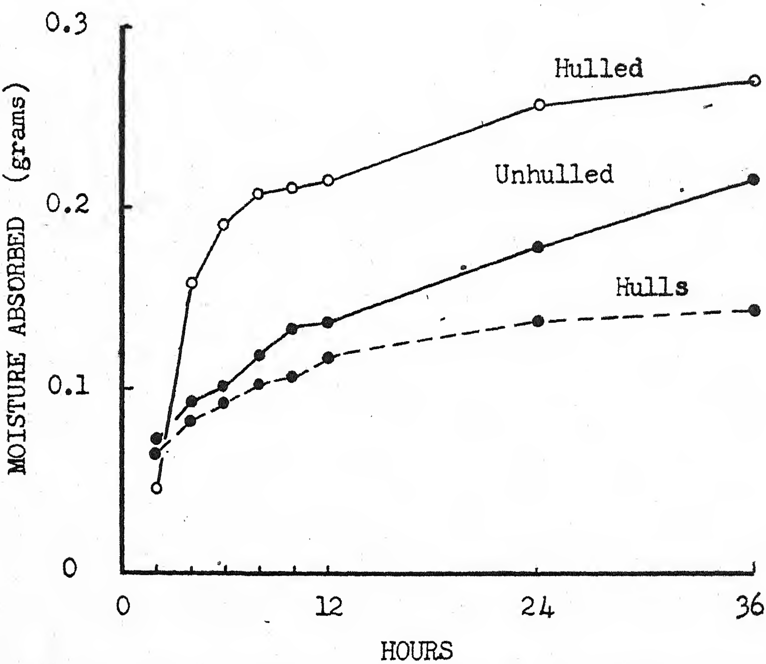


FIG. 2.—Moisture absorbed from blotter paper by hulls and by unhulled crimson clover seed in grams per 100 hulls or seed.

Wide divergence in precipitation from year to year and place to place makes this factor difficult of analysis. The soil moisture level in Piedmont, North Carolina has usually decreased as the season advanced during the period between August 1 and October 1. Rains late in the season tend to be small and insufficient for good germination of crimson clover.

Maximum emergence of crimson clover is associated with shallow seeding[2] and the upper soil layer is subject to rapid variation in moisture content. Data from field plots at Statesville, N. C., have shown that the soil moisture content at the surface should be high enough at seeding time to bring about emergence if stands are to be obtained. The soil in contact with the seed should stay moist for 3 or 4 days. Rainfall of 1 inch or more just preceding or during the

[2]MOORE, R. P. Seedling emergence of small-seeded legumes and grasses. Jour. Amer. Soc. Agron., 35:370–381. 1943.

germination period was necessary to maintain the moisture level at a high enough plane to insure stands. Using unhulled seed has helped to overcome the hazard of small and medium amounts of rainfall after seeding on dry surface soils. The use of unhulled seed has the disadvantage of being bulky and difficult to plant with machinery.

The application of superphosphate increased the crimson clover yield on Cecil soils regardless of seeding date. With applications of superphosphate, the September seedings made rapid spring growth and equaled August seedings in yield. The untreated September seedings also yielded less than untreated August seedings. The use of superphosphate did not affect emergence of crimson clover seedlings. —R. E. STITT, *Division of Forage Crops and Diseases, Bureau of Plant Industry, Soils, and Agricultural Engineering, Agricultural Research Administration, U. S. Dept. of Agriculture, the North Carolina Agricultural Experiment Station, and the North Carolina Department of Agriculture, Statesville, N. C.*

EFFECT OF UNHARVESTED SOYBEAN RESIDUES ON THE YIELD OF THE SUCCEEDING WHEAT CROP AT DIFFERENT SOIL FERTILITY LEVELS

IN AN experiment to determine the best method and rate of fertilizing a 4-year rotation of corn (rye intercrop), soybeans, wheat, and clover on a light-colored (Crosby) silt loam soil which was very low in fertility and organic matter, an opportunity presented itself to determine the effect of unharvested soybean residues on the yield of the succeeding wheat crop.

Early in September, 1942, the first year of the experiment, the soybean plots were trimmed to harvest size using a gasoline power-driven sickle-mower. The soybeans on these plot borders were green when cut. They were left where they fell, and decayed slowly to form an effective mulch.

The soybeans on the net plots were cut September 25, 1942, and were threshed October 2. The straw from each harvest area was returned to the plot from which it came. The land was disked and Fairfield wheat was drilled October 13.

As soon as the wheat crop came up, it was evident that the plants on the plot borders from which no soybeans were removed made much better growth than the plants on the adjacent areas from which the beans had been removed. This difference was very prominent during the spring of 1943; therefore, it was decided to obtain wheat yield data from both borders and plots. The data obtained (Table 1) show that, in all cases, the borders outyielded the corresponding plots. This increase in yield of the borders ranged from 6.4 bushels per acre on the untreated plots (treatment 1) to 1.0 bushels per acre on treatment 7. These differences were obtained in spite of the fact that wheat yields on all borders and plots were considerably reduced by a severe infestation of scab.

TABLE 1.—*Yield of wheat following soybeans as affected by soybean residues, Crosby silt loam, Lafayette, Ind., 1943.*

Treatment*	1943 wheat yield in bushels per acre†		
	Plots from which soybean grain was removed	Borders, no soybeans removed	Increase on borders
1	6.5	12.9	6.4
3	14.8	18.3	3.5
7	13.6	14.6	1.0
8	18.4	21.7	3.3

*1 = No fertilizer; 3 = 400 lbs. of 0–12–12 for soybeans in 1942, 800 lbs. of 0–12–12 top-dressed on wheat in spring of 1943; 7 = 800 lbs. of 0–12–12 drilled with wheat in fall of 1942; 8 = 200 lbs. of 3–12–12 drilled with wheat in fall of 1942 and 200 lbs. of 12–12–12 top-dressed on wheat in spring of 1943.

†Average of three replications.

Both plots and borders received identical fertilizer treatments. Thus, it seems that the increased yield on the borders can be explained by a combination of two factors, *viz.*, (1) no soybeans,

and therefore no plant food nutrients, were removed from the borders; and (2) in the month which elapsed between the time the soybeans were cut on the borders and the time wheat was seeded, decomposition of the green material which contained a favorable carbon-nitrogen ratio improved the physical condition of the soil and thus formed a better seedbed for wheat.—M. T. VITTUM and N. HORRALL, *Agronomy Department, Purdue University Agricultural Experiment Station, Lafayette, Ind.*

LINKAGE OF GREEN-STRIPED-2 IN SORGHUM[1]

A GREEN-STRIPED plant character in sorghum, green-striped-1, has been described in a report of one of the linkage groups.[2] A second green-striped character was found at Chillicothe, Tex., in an F_3 population of (Leoti × Ajax) in 1936.

The character green-striped-2 develops in the leaves a few days after the seedlings emerge, appearing as pale green stripes between the main vascular strands. The pale stripes gradually disappear and the tissue becomes green before the leaf reaches its ultimate size. Plants of green-striped-2 do not vary much within a population or between populations and the stripes are not so distinct as those of the more heavily striped plants of green-striped-1. The latter type shows considerable variation among plants. Other characteristics of green-striped-2 individuals are abundant tillering and small stature. Tillers frequently number 15 to 20 and average about 10 under conditions in which normal siblings average less than two tillers to the plant. The culms are relatively short and fine, leaves are short and narrow, and panicles are small, perhaps partly because of excessive tillering but probably also because of some more direct effect of the gene action. If these latter characteristics are caused by a gene or genes other than but closely associated with the one causing striping, the linkage is so close that no crossovers have been observed.

In the original F_3 population in which the character occurred and in each of the segregating populations of later crosses green-striped-2 plants comprised approximately 25% of the total, indicating a single-factor character. In the F_2 generation of green-striped-1 × green-striped-2, there were 228 normal to 178 green-striped plants among a total of 406 plants which happens to be a perfect fit for the 9:7 ratio expected if factors are independent.

LINKAGE

The association of factors for green-striped-2 (gs_2) with those for male sterility (ms_2) and awns (a) are shown in Table 1. The weighted

[1]Cooperative investigations of the Division of Cereal Crops and Diseases, Bureau of Plant Industry, Soils, and Agricultural Engineering, Agricultural Research Administration, U. S. Dept. of Agriculture, and the Texas Agricultural Experiment Station at Texas Substation No. 12, Chillicothe, Tex. Technical Series No. 848, Texas Agricultural Experiment Station.

[2]STEPHENS, J. C., and QUINBY, J. R. Linkage of the Q B Gs group in sorghum Jour. Agr. Res., 57:747–757. 1938.

TABLE I.—*Linkage of factors for green-striped-2* ($Gs_2\ gs_2$), *male sterile-2* ($Ms_2\ ms_2$), *and awns* (Aa).

Factors		Phase	Number of plants					Crossover, %
			X		x		Total	
Xx	Yy		Y	y	Y	y		
$Gs_2\ gs_2$	$Ms_2\ ms_2$	CS	1,201	165	184	259	1,809	22±1.1
$Gs_2\ gs_2$	$Ms_2\ ms_2$	RS	378	137	168	14	697	30±3.4
$Gs_2\ gs_2$	$Ms_2\ ms_2$	CB	55	16	18	51	140	24±3.6
Weighted average								23±1.0
$Gs_2\ gs_2$	Aa	CS	1,065	225	213	203	1,706	30±1.4
$Gs_2\ gs_2$	Aa	RS	285	98	117	17	517	38±3.7
$Gs_2\ gs_2$	Aa	CB	36	19	12	34	101	31±4.6
Weighted average								31±1.3

average crossover percentage[3] from F_2 and backcrossed populations segregating for $Gs_2\ gs_2$ and $Ms_2\ ms_2$ is 23 and from populations segregating for $Gs_2\ gs_2$ and Aa it is 31. These crossover percentages indicate that the factors gs_2 and a are on opposite sides of ms_2, since ms_2 and a have been reported linked with approximately 11% crossing over,[4] and add gs_2 to the ms_2–a–v_{10} linkage group.—J. C. STEPHENS, *Division of Cereal Crops and Diseases, Texas Substation No. 12, Chillicothe, Tex.*

[3]IMMER, F. R., and HENDERSON, M. T. Linkage studies in barley. Genetics, 28:419–440. 1943.
[4]STEPHENS, J. C., and QUINBY, J. R. The Ms_2 A V_{10} linkage group in sorghum. In press in Jour. Agr. Res.

BOOK REVIEW

FOOD ENOUGH

By John D. Black. Lancaster, Pa.: The Jaques Cattell Press. IX + 269 pages, illus. 1943. $2.50.

THIS book is a popularly written yet factual discussion of the food situation during and after the war. It contains many splendid diagrams and tables illustrating the pertinent points. At times matters may be slightly over-simplified, but this is needed to make this complicated topic comprehensible. After a discussion of the food requirements of the armed forces, war workers, and the civilian population, Dr. Black discusses the possibilities and means of expanding food production. In the closing chapters the role of food in the post-war world is considered in its national and international aspects.

On the whole, Dr. Black is optimistic concerning the possibilities of expanding food production in this country. "Given ten years to reorganize its agriculture and readjust its consumption, this nation could feed twice its present population at a higher level of health and working efficiency than it has ever attained." Much will depend, of course, on whether we will retain after the war the spirit of international cooperation or revert to individual and national selfishness.

We ought to be thankful for books like this in which confused and involved matters of such enormous importance are made understandable for us. And optimism from a person who is intimately associated with the development of food policies is reassuring indeed when doubts are often raised concerning our ability to fulfill our commitments to relieve hunger and starvation in the post-war world. This splendid little book is heartily recommended to all who wish to find out about the facts which govern the trend in the food situation.—Z. I. KERTESZ.

AGRONOMIC AFFAIRS

NEWS ITEMS

According to *Science*, Doctor Walter Thomas, Professor of Plant Nutrition at the Pennsylvania State College, has been awarded the Charles Reed Barnes honorary life membership for 1943 in the American Society of Plant Physiologists "for outstanding researches in the mineral nutrition of plants".

—A—

President F. W. Parker has appointed Doctor Merle T. Jenkins to represent the American Society of Agronomy on the Division of Biology and Agriculture of the National Research Council.

—A—

Doctor Sanford S. Atwood, formerly Associate Agronomist with the U. S. Regional Pasture Research Laboratory at State College, Pa., has been appointed Assistant Professor of Plant Breeding at Cornell University. Professor C. H. Myers who has been with the Department of Plant Breeding at Cornell since 1912, retired in March.

—A—

On Columbus Day, 1944, the Escuela Agricola Panamericana (School of Pan American Agriculture) will be formally opened in a fertile valley, about 25 miles from Tegucigalpa, Honduras. The school has been founded and will be maintained by the United Fruit Company, which will supply free and expert training for the youth of Central America. It is expected that the full enrollment will be 160. The course is to run for three years, with a fourth year added for those who show special proficiency and capacity for specialization. Emphasis will be placed on soil analysis, common tropical diseases and insect pests of crops and livestock, forestry, crop rotation, farm engineering, and hygiene.

—A—

Doctor Gilbeart H. Collins, Professor of Soils at Clemson Agricultural College, Clemson, S. C., is co-author with Dr. D. F. Dickerson of the University of Minnesota of a book on "General Agriculture" designed as a text for non-vocational high schools and so written as to be satisfactorily used in any section of the United States. The book, now in its eighth edition, is published by the Grand Rapids *Herald-Review*, Grand Rapids, Minn.

JOURNAL

OF THE

American Society of Agronomy

VOL. 36 JUNE, 1944 No. 6

THE INHERITANCE OF REACTION OF TURKEY-FLORENCE-1 X ORO-1 TO RACE 11 OF *TILLETIA TRITICI*[1]

O. A. VOGEL, C. E. CLASSEN, AND E. F. GAINES[2]

IN A previous paper (1)[3] a genetic analysis was given for the reactions of segregates of Turkey-Florence-1 × Oro-1 and related crosses to race 8 of *Tilletia levis* in 1940. This paper contains a genetic analysis of the reactions of the segregates of the same crosses to race 11 of *T. tritici* in 1940 and of five additional F_4 families in 1941.

MATERIAL AND METHODS

The F_1, F_2, and F_3 of the three possible combinations among Turkey-Florence-1, Oro-1, and Sel. 9 of Oro × Turkey-Florence, and the six F_4 families of Turkey-Florence-1 × Oro-1 were produced, inoculated, planted October 19, 1939, and harvested by methods previously described (1). The three parents and five additional F_4 families of Turkey-Florence-1 × Oro-1 were similarly inoculated with the same lot of T-11 used in 1939 and planted on October 17, 1940. The reaction of each plant was classified either as smut-free or smutted.

The purpose of obtaining F_1 reactions was to note the behavior of plants of the heterozygous genotype. The F_2 reactions indicate the frequency distributions of smut percentages from rows containing plants segregated from the F_1 genotype. The F_3 rows were used for the genetic analysis because each row represents the progeny of a segregate from the F_1 genotype. The 11 F_4 families represent 11 randomly chosen F_2 segregates.

EXPERIMENTAL RESULTS

The winters following the 1939 and 1940 plantings were mild during the periods of no snow cover, and there were no noticeable reductions in stand from winter injury.

[1]Cooperative investigations of the Division of Cereal Crops and Diseases, Bureau of Plant Industry, Soils, and Agricultural Engineering, Agricultural Research Administration, U. S. Dept. of Agriculture, and the Washington Agricultural Experiment Station, Pullman, Wash. Published as Scientific Paper No. 550, College of Agriculture and Experiment Station, State College of Washington. Received for publication May 22, 1943.

[2]Associate Agronomist, Division of Cereal Crops and Diseases, Bureau of Plant Industry, Soils, and Agricultural Engineering; Formerly Research Fellow in Farm Crops, Washington Agricultural Experiment Station, now Assistant Agronomist, Nebraska Agricultural Experiment Station, Lincoln, Nebr.; and Cerealist, Farm Crops Section, Division of Agronomy, Washington Agricultural Experiment Station, respectively.

[3]Figures in parenthesis refer to "Literature Cited", p. 479.

The genetic interpretations suggest at least three pairs of factors, two major and one minor. The most resistant parent, Oro-1, is CCDDee; the other resistant parent, Sel. 9, is CCddEE; and the least resistant parent, Turkey-Florence-1, is ccddEE.

The genotypes and distribution of reactions to race T-11 of the three parental varieties Oro-1, Turkey-Florence-1, and Sel. 9; the F_1, F_2, and F_3 generations of the three combinations; and also those of 11 randomly selected F_4 families are given in Table 1.

The bunt reactions in 1940 differed somewhat from those in 1941, and, therefore, the reactions are not used interchangeably.

RESULTS IN 1940

Turkey-Florence-1 × Oro-1.—The frequency distribution of the F_3 rows of Turkey-Florence-1 × Oro-1 appears to have resulted from the segregation of three pairs of factors for resistance.

The ratio of approximately 1 row within the range of Turkey-Florence-1 to 15 in the more resistant classes indicates that two of the factors, CC and DD, were from Oro-1. The third factor EE, in Turkey-Florence-1, apparently showed more resistance in 1941 than in 1940. Transgressive segregation for aabbcc, greater susceptibility than Turkey-Florence-1, was more apparent in F_4 families E, J, and K than in the F_3 or in the F_4 family B. Schlehuber (3) found a minor factor in Turkey-Florence for resistance to T-11. This factor probably is the same as the factor EE.

The high resistance of the F_1 and F_2 and the concentration of F_3 rows toward the resistance end of the frequency distribution indicate that the main factors at least are dominant for resistance. The reactions of the factors, individually and in some of the possible combinations, can be more readily observed in the related crosses and in the F_4 families.

Sel. 9 × Turkey-Florence-1.—The frequency distribution of the F_3 of Sel. 9 × Turkey-Florence-1 appears to have resulted from the segregation of a single dominant factor, Cc. The F_1 and F_2 reactions indicate that C is not completely dominant for resistance. The factor EE of Turkey- Florence-1 apparently is also contained by Sel. 9 because there is no apparent indication of transgressive segregation.

Sel.9 × Oro-1.—On the basis of the genetic interpretations of the two previous crosses, Sel. 9 and Oro-1 have CC in common, but the second factors of each are different. In order to account for the high resistance of the F_3 segregates of Sel. 9 × Oro-1, the least resistant genotype possible, CCddee, must be practically as resistant as Sel. 9. If such is the case, then DD has a greater complementary reaction with CC than does EE. The lack of any bunt in the F_1 indicates that CCDdEe is probably more resistant than CCDDee. The differences in the reactions of these resistant genotypes, however, are small and the element of chance may not have been overcome sufficiently by the populations to show definitely the relative differences in the reactions of these genotypes.

F_4 family B.—The frequency distribution of the F_4 family B is similar to that of the F_3 of Turkey-Florence-1 × Oro-1, and, therefore, probably resulted from segregation of the same genotype, CcDdEe.

F_4 family F.—The F_4 family F appears to have resulted from the same genotype as Turkey-Florence-1. The two moderately resistant rows probably resulted from some error or from field hybridization of two of the florets of the F_2 plant from which this F_4 family was derived.

F_4 family C.—could have resulted from anyone of the three genotypes, CCDDEE, CCDDEe, or CCDDee. The genoytpe CCDDEE is suggested, because all of the 7,195 plants were bunt-free.

F_4 family E.—The frequency distribution of the F_4 family E probably resulted from the segregation of the genotype ccDdee. Apparently, a considerably larger population is needed to show more clearly the range of reactions for the genotype ccDDee. If the range of reactions of the genoytpe ccDDee extends only to the 32.5% class, two more rows would be needed to fit significantly a 1:3 hypothesis. The genotype ccDdee appears to be more resistant than the Turkey-Florence-1 parent. The rows in the four most susceptible classes could be mostly from the genotype ccddee.

F_4 family A.—In F_4 family A there are 23 rows within the class range of the Turkey- Florence -1 parent, indicating these to be of the ccddEE genotype. In a 1:2:1 ratio the above 23 are within 1.5 of the expected number. This 1:2:1 segregation differs essentially from that of the F_3 of Sel. 9 × Turkey-Florence -1 in that the intermediates of F_4 family A are more resistant. These more highly resistant intermediates could have resulted from the segregating genotype ccDdEE. The resistant rows could be from ccDDEE.

F_4 family D.—The frequency distribution of the segregates of F_4 family D suggests a 1:2:1 ratio somewhat similar to that of F_4 family A. Some of the intermediates, however, are distributed similarly to those in the F_3 of Sel. 9 × Turkey-Florence -1. In the absence of additional data it is suggested that F_4 family D probably came from the same genotype as F_4 family A, ccDdEE. However, the possibility that it came from the two F_2 genotypes ccDdEE and CcddEE is supported by the wide range of the intermediate segregates, as well as the fairly indistinct separation of both the resistant and susceptible rows from the intermediates.

RESULTS IN 1941

In 1941, Turkey-Florence -1 averaged less than one-half as smutty as in 1940. Also, it was more variable in its reaction as is indicated by the frequency distribution of the 47 rows. The reactions of Oro-1 and Sel. 9 were more nearly alike in 1941 than in 1940.

F_4 family G.—The F_4 family G produced less bunt than Oro-1 in 1941, suggesting that it resulted from a genotype more resistant than CCDDee. If, as was suggested for the reaction of F_4 family C, the genotype CCDDEE could also produce only bunt-free plants in 1941, the F_4 family G could have resulted from the segregating genotype CCDDEe.

F_4 family H.—The average percentage of bunt of F_4 family H and Oro-1 are the same, and the frequency distributions of the two are very similar, indicating that both probably resulted from the same genotype.

TABLE 1.—*Genotypes and distribution of reaction to race T-11 of the three parental varieties Oro-1, Turkey-Florcene-1, and Sel. 9; the F_1, F_2, and F_3 generations of the three possible combinations; and 11 randomly selected F_4 families of Turkey-Florence-1 × Oro-1.*

Cross or parent	Generation	Genotype	Number of rows in each class																					Total No. of rows	Average percentage of bunt
			0	2.5	7.5	12.5	17.5	22.5	27.5	32.5	37.5	42.5	47.5	52.5	57.5	62.5	67.5	72.5	77.5	82.5	87.5	92.5	97.5		
1940 Results																									
T-F-1	Parent	ccddEE	—	—	—	—	—	—	—	—	—	—	—	1	1	1	6	9	23	15	12	4	—	72	79.3
Sel. 9	Parent	CCddEE	41	30	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	72	0.8
Oro-1	Parent	CCDDee	71	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	72	-0.02
T-F-1	F_1	CcDdEe	—	1*	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	1.0
Oro-1	F_2	CcDdEe	—	—	4	8	6	2	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	20	14.8
	F_3	CcDdEe	111	40	32	31	19	20	16	10	8	7	5	5	1	1	1	—	4	3	2	4	—	320	14.7
	F_4-A	ccDdEE	20	5	8	8	16	8	3	2	2	3	—	1	1	5	2	5	1	6	2	—	—	98	27.5
	F_4-B	CcDdEe	34	16	13	8	7	5	7	2	1	3	—	—	—	—	—	1	—	1	—	1	1	100	12.7
	F_4-C	CCDDEE	119	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	119	0.0
	F_4-D	ccDdEE†	13	7	7	2	9	5	7	11	2	3	3	5	3	1	3	1	4	2	1	—	—	89	29.4
	F_4-E	ccDdee	1	2	2	1	2	2	3	—	1	3	5	5	7	6	15	6	3	6	6	6	6	88	62.5
	F_4-F	ccddEE	—	—	—	1	—	—	1	—	—	—	—	—	2	2	9	7	11	19	12	9	—	73	78.5
Sel. 9																									
Oro-1	F_1	CCDdEe	1‡	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	0.0
	F_2	CCDdEe	17	3	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	20	0.2
	F_3	CCDdEe	218	38	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	257	0.3
Sel. 9																									
T-F-1	F_1	CcddEE	—	—	1§	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	9.0
	F_2	CcddEE	—	—	—	—	1	1	5	7	6	—	—	—	—	—	—	—	—	—	—	—	—	20	32.0
	F_3	CcddEE	48	12	1	2	12	16	25	22	18	12	11	5	3	1	5	6	11	25	10	5	—	250	37.5

1941 Results

T-F-1	Parent	ccddEE	—	—	—	—	2	2	8	5	9	7	7	3	2	—	2	—	—	—	—	—	—	47	38.4
Sel. 9	Parent	CCddEE	39	4	3	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	46	0.7
Oro-1	Parent	CCDDee	42	4	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	47	0.3
T-F-1																									
Oro-1	F_4-G	CCDDEe	121	4	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	125	0.06
	F_4-H	CCDDee	118	7	1	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	127	0.3
	F_4-I	CcDdEE	56	24	16	11	6	5	3	3	2	2	1	1	—	—	—	—	—	—	—	—	—	130	8.0
	F_4-J	ccDdEe	10	11	6	4	6	7	8	4	6	8	2	—	4	4	2	—	3	1	—	—	—	86	27.0
	F_4-K	CcddEe	9	8	5	4	3	2	7	10	11	12	8	7	6	5	2	3	6	1	1	—	—	110	37.0

*Average of 225 plants.
†Could have resulted from a mixture of ccDdEE and CcddEE.
‡Average of 218 plants.
§Average of 232 plants.

F_4 family I.—The F_4 family I appears to have resulted from segregations of the two main factors C and D. In view of the relatively small difference between the parental reactions, the reactions of the various genotypes from CcDdEE would be rendered more or less indistinct by the overlapping expected.

F_4 families J and K.—The F_4 families J and K appear to have resulted from heterozygous two-factor genotypes, each of which segregated for the most susceptible genotype, ccddee. As was suggested previously, certain combinations of D and E in F_4 family A produced higher complimentary resistance than did corresponding combinations of C and E in the F_3 of Sel. 9 × Turkey-Florence-1. It is suggested, therefore, that F_4 families J and K resulted from ccDdEe and CcddEe, respectively.

SPECIAL COMPARISON OF REACTIONS TO T-11 AND T-13

Holton and Rodenhiser (2) have shown that their T-11 consisted of a mixture of T-11 and T-13. Consequently, the T-11 inoculum used in these genetic studies was actually a mixture of these two races. The reactions of 64 specially selected F_3 and F_4 rows to the so-called T-11 inoculum used in 1939 and 1940 and to pure T-13 appeared to be very similar in special studies conducted in 1940. Further studies of a comparison of the reactions to T-11 and T-13 cannot be made until after a supply of pure T-11 becomes available.

SUMMARY

Three crosses, consisting of the three possible combinations of Oro-1, Turkey-Florence-1, and Sel. 9 of Oro × Turkey-Florence, were studied for the inheritance of reaction to race 11 of *Tilletia tritici*.

The F_1, F_2, and F_3 generations of all three crosses and six randomly selected F_4 families of Turkey-Florence-1 × Oro-1 were tested for reaction during 1940 under identical environmental conditions. Five additional F_4 families were tested in 1941.

At least three factors, two major and one minor, appeared to account for the segregation of reaction of Turkey-Florence-1 × Oro-1. Oro-1, the most resistant parent, carried the two major dominant factors. Turkey-Florence-1 carried the minor dominant factor for resistance.

Segregation of the crosses of Sel. 9 with Oro-1 and Turkey-Florence-1 indicate that Sel. 9 carries one of the two major factors of Oro-1 and the minor factor of Turkey-Florence-1.

Three of the 11 randomly chosen F_4 families appeared to have come from homozygous genotypes; one like Oro-1, the other like Turkey-Florence-1, and the third appeared to have all three factors of the two parents.

Each of seven F_4 families appeared to have come from a different heterozygous genotype; one segregating for three factors, three for two factors, and three for one factor.

One F_4 family appeared to have come either from a genotype segregating from one factor or from a mixture of two genotypes, each segregating for one factor.

The presence of the new race, T-13, in the T-11 inoculum did not appear to alter the so-called T-11 reactions sufficiently to be noticeable.

LITERATURE CITED

1. CLAASSEN, C. E., VOGEL, O. A., AND GAINES, E. F. The inheritance of reaction of Turkey-Florence-1 × Oro-1 to race 8 of *Tilletia levis*. Jour. Amer. Soc. Agron., 34:687–694. 1942.
2. HOLTON, C. S., AND RODENHISER, H. A. New physiologic races of *Tilletia tritici* and *T. levis*. Phytopath., 32:117–129. 1942.
3. SCHLEHUBER, A. M. The inheritance of reaction to physiologic races of *Tilletia tritici* (Bjerk.) Wint. in a winter wheat cross. State College of Washington Sci. Paper 392. 1938.

ABSOLUTE VALUES IN FERTILIZER EXPERIMENTS[1]

O. W. WILLCOX[2]

THE writer has published several papers on the use of the standard yield diagram in the interpretation of field experiments with plant nutrients (1, 2, 3, 4, 5, 6, 7).[3] To conclude the series another example (8) will be presented. This particular example has been chosen, first, because it illustrates two rather common types of aberrancy in the results of field tests with fertilizers; and secondly, because it affords a basis for comment on the current misplaced use of statistical methods in the evaluation of this kind of field tests.

Two separate fields, one with and one without green manuring, were laid out in the conventional manner for a test of a potash fertilizer with a certain variety of sugar cane. There were four treatments, each in four replications. After the first year two successive ratoon crops[4] were taken. The first of these ratoon crops happened to grow in a poor season and gave a relatively low yield. The following season was a good one and the yields were larger. The average yields from the four treatments in the two seasons, recalculated in the customary manner to obtain "diagram units" coming within the scale of the yield diagram, are given in Table 1 and have been used in constructing the graphs of Figs. 1 and 2.

TABLE 1.—*Saito's field test with potash and sugar cane.*

Series	Potash used, baules	Unit yields and their ratios					
		No green manure			With green manure		
		Poor season	Good season	Ratios	Poor season	Good season	Ratios
I	0.0	7.6	10.9	1.43	12.4	17.3	1.40
II	0.88	11.4	16.5	1.45	13.9	19.4	1.40
III	1.76	11.9	18.2	1.52	14.1	19.7	1.40
IV	3.70	13.2	19.1	1.44	13.5	19.1	1.41

Referring first to the yield from the field without green manuring, Fig. 1, curve P, the results exhibit a mixture of normality and aberrancy. The yield from series I (no potash) is abnormal and out of line with the yields from the three potash treatments, series II, III, and IV. These three points conform to curve $A = 13.5$, while series I lags behind on curve $A = 11.0$. A similar arrangement of the points is observed in the results on the same field in the good season (Fig. 1, curve G), with the difference that in the good season the yields from all series were greater. Here, the II, III, and IV yields fall on curve $A = 20$, while I fails to rise above curve $A = 16$.

[1]Received for publication October 13, 1943.

[2]Consulting Agrobiologist, 197 Union St., Ridgewood, N. J.

[3]Figures in parenthesis refer to "Literature Cited", p. 486.

[4]Regrowths following previous cutting.

The characteristic of this particular type of discrepancy is a marked spread between the yield from the untreated plots and the yield from the first increment of added potash. This latter yield and the yields from the higher increments of fertilizer then conform to a normal yield curve. The writer has frequently encountered this kind of mixed result, and at the moment has no sure explanation for it. A choice might be made between two hypotheses. First, the real normal curve for

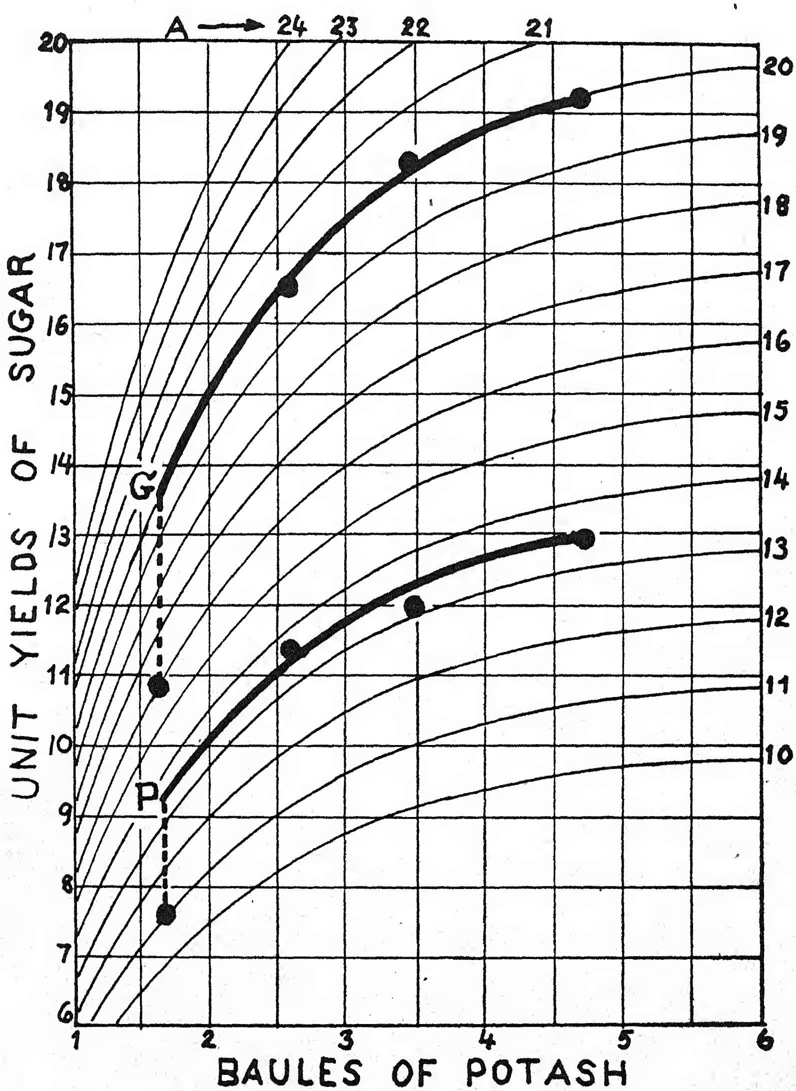


FIG. 1.—Cane potash experiment; no green manure. P, poor season; G, good season.

this field in the poor season may actually be defined by points I and II. Points III and IV would then represent a deflection from the normal, due to a yield-depressing effect of the rather large increments of potash. However, since the potash treatments produced a 3-point curve having all the appearance of normality, the existence of yield-depression is unlikely. Another hypothesis would assume that the added potash acted on some unknown soil condition in such a way

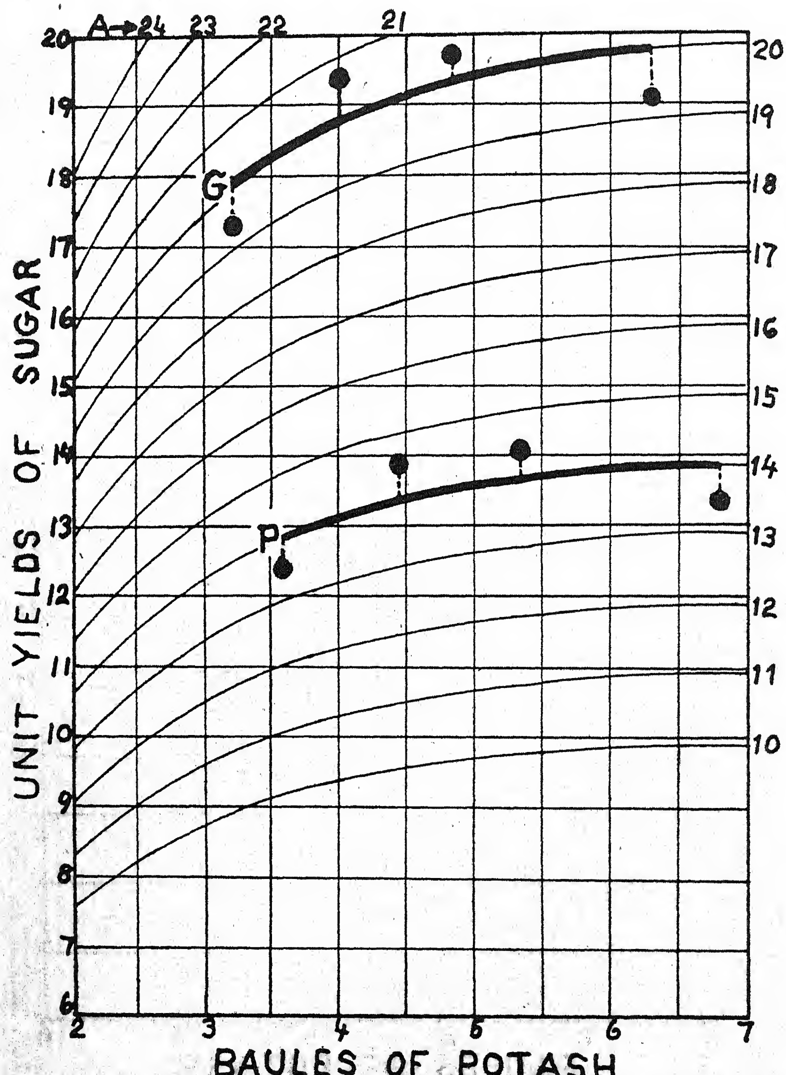


FIG. 2.—Cane potash experiment; with green manure. P, poor season; G, good season.

as to establish a fertility level qualitatively different from that of the untreated field. It may be noted that the same variation recurred in the good season, indicating that this aberrancy is not related to seasonal changes.

Referring next to the poor-season crop on the field with green manuring, Fig. 2, curve P, we encounter another rather common type of discrepancy. The four yield points cannot be made to fit smoothly on any of the normal yield curves, but arrange themselves in the form of an inverted crescent, with curve $A = 14$ as the median. Here again, we might assume that points I and II really define the normal yield curve, with points III and IV on a depression limb. This assumption is more probable than in the case of the field without green manure, as point IV here shows a decrease when compared with points III and II. As in the field without green manure, the yields from the green-manured field in the good season are larger and closely parallel the results of the poor season, the four points being spaced in the same inverted crescent pattern.

For the main purpose of this paper the point of particular interest about this example is the paralellism or homology of the results on the two fields in the two seasons. This homology becomes apparent when the ratio of the yield of each treatment in the poor season to the yield from the same treatment in the good season is taken. In each field the ratio is a constant for that field. In the field without green manure the ratios closely average 1.46 (fifth column of Table 1). In the field with green manure, the ratios closely average 1.40 (last column of Table 1).

The reason for this homology of results and constancy of ratios is that what we are seeing is an attained equilibrium, or state of balance, between two interacting forces that in any given case have fixed dimensions. On the one hand is the vital energy or specific "quantity of life" that resides in the variety which is serving as the test crop and by virtue of which the plants are able to produce a certain maximum yield. On the other hand, the percentage of the total quantity of life inherent in the plants that will be evoked depends on the actual amount of growth-promoting force that the environment is able to supply. Each of these two interacting forces, then, has a definite magnitude. Being possessed of definite magnitudes, these two forces are natural constants. The product of their interaction (the crop) is therefore also a natural constant. One of the quantitative rules of nature is that a given amount of effect is always underlain by a proportionate amount of cause. Another is that natural phenomena are reproducible; when a certain amount of force acts on a certain object under certain circumstances to produce a certain quantitative effect, exactly the same quantitative effect will be reproduced when the same force again acts on the same object under the same circumstances.

These natural laws are known in a general way to all professional agronomists, of course, and possibly to one or more professors of experimental statistics. The prevalence of the current statistical concepts in this division of field experimentation, however, suggests that many agronomists and their statistical mentors fail to see how these laws govern the result of a field experiment with a plant nutrient.

To repeat, the ratios observed in Saito's 2-year field test are constants because the forces that produced them were natural constants. The circumstances of the experiment, both internal and external, were such that the phenomena of growth and yield could unfold under fixed conditions, except for controlled variations in the amounts of potash used and for a seasonal change that bore equally on all the original factors. The test plant (POJ 2725) was the same on all plots in both seasons. No replanting for the second crop was necessary because the second crop was ratooned from the preceding one; that is, the two crops were grown from the same stools. Hence, the possibility of biological variation was reduced practically to zero. Cultural operations were limited to the usual weed-killing tillage and harvesting, all done under competent supervision. Thus, operative errors were also practically absent.

Suppression of these sources of experimental error allowed the individual plots of soil to show their intrinsic qualities. As in all field tests the world over, none of these plots was exactly like any of the others and all gave different yields. Each plot of soil evidently had its own coefficient of fertility, no doubt compounded of a specific soil reaction (pH), structure, permeability, colloid content, humus content, moisture-supplying capacity, microbiological population, etc., and content of the major and minor plant nutrients, all summing up to a certain definite amount of crop-producing energy. The amount of yield produced by each plot was therefore a definite numerical characteristic of that plot, a natural constant that is reproducible under the same circumstances. The yield of each plot being a natural constant, the sum of the yields of the untreated plots is also a constant, and the same is true of the yields of the treated plots. The average yield from each series is necessarily a constant, and so we obtain four natural constants for drawing each of the yield curves. These points represent absolute or fixed values, to which nothing can be added and from which nothing may be subtracted by statistical analysis.

The yields in the good season were uniformly higher than in the poor season because a new condition was introduced, namely, a more favorable climatic condition. This new condition, however, bore equally on all plots, and of itself made no change in the relative fertility indexes of the plots. Each series therefore finished the second season in the same relative order as in the first. This is why we see an almost perfect homology in the results of this 2-year experiment on these fields. The rule of strict proportionality between cause and effect in crop production is once more conclusively, if indirectly, demonstrated.

It may be noted that this discussion has proceeded without use of analysis of variance. The writer's only concern here with statistical methods is to point out that, as currently conceived and applied to field tests with plant nutrients, analysis of variance is being used in disregard of the two universally valid principles mentioned above, namely, the rigidly quantitative relation between cause and effect and the reproducibility of natural phenomena. In the statistical view, the reproducibility of the results of a field test is held to be conditional on statistical "significance", which must exceed a certain figure that de-

pends on the degree of variation between the yields of individual plots and the extent and distribution of overlapping yields between treatments. All such statistical calculations, involving the aforesaid quantitative variations, especially those dealing with small "populations", leave a wider or narrower margin for the play of chance, which is usually assessed as odds for or against reproducibility.

Opposed to this is the agrobiologic view which, proceeding from the principle of the absolute reproducibility of natural phenomena under parallel conditions, takes it for granted that where the action of the force (the nutritive medium) on the object (the crop) is immediate and direct (as it is in a field test with a plant nutrient), the result must be accepted as an absolute value and wholly reproducible under parallel conditions, without margin for chance. In practice the difference amounts to this: Where the statistician writes $Y = M \pm N$, wherein $\pm N$ indiscriminately engulfs all imaginable sources of real or presumed error including the effects of soil variability, biological variations in the test plant, and operative faults of manipulation, the agrobiologist writes $Y = M \pm i$, wherein $\pm i$ encloses only the relatively small and generally neglible errors due to undetermined faults of manipulation and in which neither soil variability nor biological variations (competent work presupposed) have any part.

To repeat, the only real errors that can affect the accuracy of a properly conducted field test with a plant nutrient are faults of manipulation, which are subject to practically complete exclusion by a competent operator. To drag in the relatively huge discordances in soil quality, thereby creating an unreal margin for chance, is scientifically unwarranted, unnecessary, and frequently productive of confusion and futility. The common sense thing to do is simply to accept the average yields from the treatments at their face values and graph them on the standard yield diagram, where their degrees of normality or aberrancy will be disclosed.

At the same time it is to be noted that these strictures on the use of analysis of variance with field tests on plant nutrients are not extended to certain other categories of field experiments such as field comparisons of different varieties of crop plants, for instance. The difference here is that in field tests with plant nutrients there is *no outside interference* with the reaction between the soil and the plants, and hence there is no real margin for chance even though soil variability be great. On the other hand, where the object is to determine the relative yielding abilities of different varieties, soil variability represents an outside interference, and in the absence of corrective information may properly be dealt with by statistical methods.

One practical objection to the statistical method in this field is that by confusing the large soil variations, that are specific characteristics of integral components of the experimental system, with the small and generally negligible operative errors, it often unwarrantably stamps a well-conducted field test with a fertilizer as futile or wasted effort. Unless the calculated significance exceeds a certain figure, there is supposed to be a chance that the visible result may not reliably represent the real situation on the field. The writer has noted numerous instances where the average increase of yield from the treatment over

the control plots was 3 or 4 tons (large enough to be profitable), whereas the calculated requirement for significance amounted to 5 tons or more. In such cases, a statistician might advise the farmer against taking the risk. But on agrobiologic grounds, and specifically the principle of the reproducibility of natural phenomena, there is no reason for doubting the authenticity of the increase. After all, what the experiment really shows are the ratios between the fertilities of the treated and the untreated plots; and irrespective of how the plots differ among themselves, these ratios are natural constants which may persist through good and bad seasons that bear equally on all.

LITERATURE CITED

1. WILLCOX, O. W. The fertilization of sugar cane. I. A simple graphical method of evaluating tests with fertilizers. Facts About Sugar, 35, No. 12:33–37. 1940.
2. ———. The fertilization of sugar cane. II. The agrobiologic evaluation of some potash tests. Sugar, 36, No. 6:26–29. 1941.
3. ———. The fertilization of sugar cane. III. Sugar, 36, No. 11:26–27. 1941.
4. ———. A critique of field experiments with plant nutrients. Amer. Fert., 95, No. 5:5–7, 26; No. 6:5–7, 24. 1941.
5. ———. Interpretation of Olsen and Shaw's field tests by the Mitscherlich-Baule theorem and the universal yield diagram. Jour. Amer. Soc. Agron., 35: 454–459. 1943.
6. ———. Yield-depression effect of fertilizers, and its measurement by the universal yield diagram. Jour. Amer. Soc. Agron., 36:20–31. 1944.
7. ———. Further interpretations of field tests by the Universal yield diagram. Jour. Amer. Soc. Agron., 36:386–392. 1944.
8. SAITO, TETSUZO. The effect of potash fertilizer on sugar cane and the determination of its optimum application. Report Govt. Sugar Exp. Sta., Tainan, Formosa, Japan, No. 8. 1940. (English summary.)

RELATIVE PALATABILITIES OF GRASSES UNDER CULTIVATION ON THE NORTHERN GREAT PLAINS[1]

GEORGE A. ROGLER[2]

THERE has been a great increase in the use of cultivated or domesticated grasses in the northern Great Plains during the last 10 years. Large acreages of abandoned land and cultivated areas which were marginal or submarginal for crop production have been seeded to grasses of this type. In addition, many smaller farm plantings have been made. This has done much not only to reduce erosion but to help in rebuilding hay and pasture reserves as well as aiding in restoration of the soil to its original productivity and structure. More recently, great emphasis has been placed on the use of grasses in mixtures. In spite of the recognized advantage of mixtures, in the Northern Plains, few experimental data are available. The actual inter-relationships of associated plants and their maintenance under grazing need further investigation. As a guide to the proper compounding of seed mixtures and subsequent management of stands obtained, investigations to determine the relative palatability of various species and strains were initiated in 1937 in connection with the long-time grazing experiment at the Northern Great Plains Field Station, Mandan, N. Dak.

Palatabilities or preferences in themselves are sometimes misleading. Cattle will show a preference for certain grasses if they have a chance for selection, but if restricted to a more or less unpalatable grass they will ordinarily do as well as those restricted to a more palatable one, providing of course, that both are of equal nutritive value and productivity. On the other hand, palatability studies are useful in determining when certain grasses become palatable or unpalatable and give an indication of what might be expected when certain combinations of grasses are used together in mixtures.

REVIEW OF LITERATURE

Published information on the palatability of pasture plants in the United States is limited. European workers appear to have given more consideration to the question of palatability, but most of the pasture grasses studied are not adapted to the Plains region of this country.

White, *et al.*(8)[3] list bromegrass as having the highest palatability of seven grasses tested at the Cornell University Agricultural Experiment Station. In this trial, bromegrass was the only species studied that is adapted to the Northern Plains. These investigators also found that application of nitrate of soda and lime

---

[1]Cooperative Investigations between the Divisions of Dry-land Agriculture and Forage Crops and Diseases, Bureau of Plant Industry, Soils, and Agricultural Engineering, Agricultural Research Administration, U. S. Dept. of Agriculture, and the North Dakota Agricultural Experiment Station. Also presented at the annual meetings of the Society held in Cincinnati, Ohio, November 10 to 12, 1943. Received for publication December 2, 1943.

[2]Associate Agronomist, Division of Dry-land Agriculture and Forage Crops and Diseases, Bureau of Plant Industry, Soils, and Agricultural Engineering.

[3]Figures in parenthesis refer to "Literature Cited", p. 496.

improved the palatability of most species. Bender (3) found that nitrogen-treated grass was more palatable than that grown without nitrogen.

Wilkins and Hughes (9) pointed out that various species differed in palatability. Canada bluegrass, bromegrass, and timothy were preferred. Reed canary, Kentucky bluegrass, redtop, tall meadow oat, slender wheat, crested wheat, and rough-stalked meadowgrass were eaten moderately and about equally.

Factors affecting palatability have been investigated by Beaumont, *et al.*(2). They found that stage of growth affected palatability. There was little discrimination when grasses were 2 to 4 inches high, but when 4 to 6 inches high definite preference for certain species was shown by cows. Among those tried, reed canary was one of the lowest in palatability. Breaking strength was used as a measure of toughness of leaves and an attempt was made to relate toughness to palatability, but reed canary, one of the least palatable grasses in the test, was the least tough. They also found that applications of nitrogen increased the palatability.

Archibald, *et al.* (1) summarized 7 years of investigational work on chemical composition and palatability to cows of certain grasses and legumes. On the basis of preference the rating of the grasses was without exception in the order of their vitamin A content, and with one exception in the order of their succulence. In general, also, the cows preferred those with a relatively high content of either extract, soluble ash, and magnesium, and with a low content of fiber. Nitrogen (protein) content of the grasses apparently had little if any relation to their palatability.

Davies (4) used sheep in a study of palatability and states that reed canary was one of the least palatable of the grasses tested. The chief factor in palatability was found to be succulence, and consequently it depended upon the period of year and on the degree of grazing. Stems were rejected and leaves preferred to inflorescences. Harshness or hairiness of foliage lowered the palatability.

Stoddart and Smith (7) state that, "The term palatability originally was used to apply to the avidity with which an animal ate the plant, but it came to be used in quite a different sense and occurred so universally in the literature as applied to the percentage of the plant consumed under proper grazing that its meaning has been almost lost. It would seem wise, therefore, to discard the term and use the word preference to refer to the taste an animal displays for any plant."

The establishment of the palatability pasture in which the investigations of this paper were conducted has been discussed by Sarvis (6) in relation to the grazing experiment as a whole.

EXPERIMENTAL PROCEDURE

The initial planting for preliminary palatability trials was made on August 11, 1937. A total of 42 rod square plots was planted in two series. Stands of 15 species were established, each species being represented by from one to seven strains. Yearling Hereford steers were given free access to all plots in 1938 and 1939 for a period in July. Yearling Hereford steers were also used in all subsequent tests.

In the early fall of 1938 and the spring of 1939, 24 plots from 1/10 to 1/2 acre in size were seeded to 13 species of grasses, some of them being represented by as many as three strains. Thirty duplicate rows 36 inches apart and 186 feet long were also seeded to the same species and strains with the addition of a few species and strains not represented in plots. The rows were cultivated and kept free of weeds during the course of the experiment. A mixture of grasses was seeded on approximately 1 acre which filled out a so-called 6-acre palatability pasture.

From 1939 to 1943, inclusive, steers were allowed free access to the entire pasture, except the rows of warm-season grasses, from the beginning of the grazing season until all forage was gone. The rows of warm-season grasses were grazed at different stages of maturity and for different periods during this time.

In the collection of data all grasses were grouped into one or the other of two broad classifications, based on the period of maximum vegetative growth. One was designated the cool-season group and the other the warm-season group. Cool-season grasses are those that make their maximum vegetative growth during the spring and fall with a lesser amount of growth during the hot part of the summer. These grasses start growth quickly after the ground thaws out in the spring, and if moisture conditions are favorable in the fall, they continue growth until stopped by cold. Warm-season grasses make their maximum growth after the last frost in the spring and cease growing by the time or upon the advent of the first hard frost

in the fall (5). The scientific and common names of the cool- and warm-season grasses used in these studies are shown in Table 1.

TABLE 1.—*Cool-season and warm-season grasses used in the palatability studies.*

Common name	Scientific name
	Cool-season Grasses
Crested wheatgrass	*Agropyron cristatum* (L.) Gaertn.
Western wheatgrass	*Agropyron smithii* Rydb.
Slender wheatgrass	*Agropyron trachycaulum* (Lk.) Malte.
Bromegrass	*Bromus inermis* Leyss.
Canada wild-rye	*Elymus canadensis* L.
Russian wild-rye	*Elymus junceus* Fisch.
Indian ricegrass	*Oryzopsis hymenoides* (Roem. and Schult.) Ricker.
Reed canary grass	*Phalaris arundinacea* L.
Feather bunchgrass	*Stipa viridula* Trin.
	Warm-season Grasses
Big bluestem	*Andropogon furcatus* Muhl.
Sandhill bluestem	*Andropogon hallii* Hack.
Little bluestem	*Andropogon scoparius* Michx.
Side-oats grama	*Bouteloua curtipendula* (Michx.) Torr.
Blue grama	*Bouteloua gracilis* (H.B.K.) Lag.
Buffalo grass	*Buchloë dactyloides* (Nutt.) Engelm.
Sand reedgrass	*Calamovilfa longifolia* (Hook.) Scribn.
Weeping lovegrass	*Eragostis curvula* (Schrad.) Nees.
Switchgrass	*Panicum virgatum* L.

The trials as they were carried on were relatively simple and exploratory in character. The primary purpose was to determine the preferences of the steers for the various grasses throughout the season. No attempt was made to determine nutritive values in relation to preferences, because such studies were considered to be beyond the scope of the experiment at the time it was started. Future studies should include investigations not only of preferences and nutritive values but of total production per strain or species as well.

In conducting the experiment a high intensity of grazing was used at all times, so that grasses that were not so palatable would be eaten after the more palatable ones were cleaned up. The method of recording data was by an estimate of the foliage cover or top growth removed during various intervals. The length of intervals between estimates depended upon the time during the season, the amount of moisture and subsequent recovery or rate of growth, and the rate of defoliation by the steers. Notes were taken more frequently in the early part of the season. When 80% of the foliage was removed the grass was considered to be as closely grazed as good grazing management should permit.

Except in the case of Fairway and Standard crested wheatgrass, there was little difference in palatability between strains within any one species. The data for all strains within each species for each period and for all years were averaged to give the relative palatability at specific periods during the season. The seasonal palatability rating was based on the average of all estimates in all years. Calculated palatability ratings were determined by assuming a perfect rating of 80 for bromegrass and big bluestem. Since palatability tables usually list 80 as the highest factor consistent with good management practices, the calculated ratings give a better comparison with values that have been established previously. Estimates of foliage removed were, in general, the same on all replications regardless of size of plots. Detailed statistical analyses were impossible because of the large number of variables. They were not considered necessary, however, because of the wide differences that prevailed.

RESULTS

RELATIVE PALATABILITY OF COOL-SEASON GRASSES

Pronounced differences in the palatability of cool-season grasses planted in plots were evident shortly after the steers started to graze in the spring. These differences were apparent in spite of the fact that the small amount of new growth on all grasses appeared succulent and desirable for grazing at that time. Data shown in Table 2 indicate that bromegrass and feather bunchgrass were eaten with avidity during the first 5 days in comparison to many other species. Fairway crested wheatgrass was scarcely touched, while strains of Standard crested wheatgrass which appeared coarser were well grazed. Other grasses were also avoided.

As the grazing season advanced, the forage use of all species was gradually increased, bromegrass remaining highest in preference and reed canary lowest at all times. Russian wild-rye, even though appearing very desirable for grazing, was avoided until the latter part of June when the steers began grazing it. This would indicate that this species might be desirable for use in mixtures with grasses of early palatability in order to lengthen the grazing season. Unpublished data on the use of Russian wild-rye in mixture with crested wheatgrass and bromegrass have borne out the fact that this species is not grazed until later in the season. Lack of late-season data for slender wheatgrass and Indian ricegrass made it necessary to estimate their seasonal order of forage use. Bromegrass, Standard crested wheatgrass, western wheatgrass, slender wheatgrass, and feather bunchgrass were all highly palatable under close grazing throughout the entire season. Canada wild-rye was highly palatable except during the first 5 days of grazing. In 1943 this species was one of the highest in palatability, even during the first 5 days. Fairway crested wheatgrass remained low in palatability until practically all other grasses were grazed down closely. Most of it was then eaten.

The order of forage use of the various grasses changed from time to time during the different seasons, but the average of all estimates for all years is most important in determining the correct composition of mixtures or as an indication of proper management.

Cool-season grasses planted in rows made considerable more growth and more rapid recovery than those in plots and were grazed more intensively. The order of forage use in rows as shown in Table 3 indicates slight differences from that in plots, but the same species exhibited high palatability or low palatability in both types of plantings.

RELATIVE PALATABILITY OF WARM-SEASON GRASSES

Data collected on the palatability of warm-season grasses from 1940 to 1943 were taken primarily from row plantings. Heavy weed infestations in the warm-season grass plots, lack of good establishment, and thinning of stands resulted in incomplete data that could not be summarized. The same general order of preference was shown in rows, in 1940, 1941, and 1943, as that on solid plots in 1938 and 1939. Since, in most cases, the rows were grazed during the early season, little, if any, difference in palatability from that on plots would be expected.

TABLE 2.—*Relative palatability of various cool-season grasses in plots during five periods of grazing and seasonal average, 1940 to 1943, inclusive.**

Grass	No. of plots	No. of strains	Four-year average percentage of foliage removed by grazing after					Average of individual estimates of foliage removed, %	Average order of forage use, seasonal basis	Rating based on 80 for bromegrass
			5 days	15 days	30 days	45 days	80 days			
Bromegrass	4	2	27.2	64.2	82.5	86.5	96.3	72.0	1	80
Standard crested wheatgrass	11	4	13.4	39.7	67.8	74.0	90.0	56.3	2	60
Western wheatgrass	7	4	21.3	35.6	71.2	70.7	92.1	55.7	2	60
Slender wheatgrass	2	2	Trace	43.0	76.3	—	—	—	2	60
Feather bunchgrass	4	2	35.0	41.0	68.3	70.6	85.0	58.5	2	60
Canada wild-rye	2	2	2.5	32.1	67.5	52.5	95.0	45.8	3	50
Indian ricegrass	1	1	20.0	30.0	60.0	40.0	—	—	4	50
Russian wild-rye	4	1	2.0	8.8	42.5	52.0	88.8	35.8	5	40
Fairway crested wheatgrass	3	1	Trace	15.4	35.0	50.8	83.3	30.9	6	30
Reed canary	1	1	0.0	Trace	Trace	5.0	30.0	5.7	7	10

*Grazed by yearling Hereford steers from May 16 to July 30, 1940; May 28 to July 30, 1941; May 16 to June 30, 1942; May 11 to July 30, 1943.

TABLE 3.—*Relative palatability of various cool-season grasses in rows during five periods of grazing and seasonal average, 1941 to 1943, inclusive.**

Grass	No. of rows	No. of strains	Three-year average percentage of foliage removed by grazing after					Average of individual estimates of foliage removed, %	Average order of forage use, seasonal basis
			5 days	15 days	30 days	45 days	80 days		
Bromegrass.....	4	2	23.0	78.3	76.3	83.8	97.5	68.3	1
Western wheatgrass.........	2	1	26.7	70.0	77.5	80.0	95.0	65.9	2
Standard crested wheatgrass....	10	4	15.3	68.7	66.0	70.5	95.0	59.5	3
Slender wheatgrass.........	2	1	13.3	80.0	82.5	75.0	—	—	3
Canada wild-rye	2		3.3	73.3	72.5	72.5	95.0	59.2	3
Fairway crested wheatgrass....	2	1	8.3	50.0	45.0	55.0	90.0	45.8	4
Russian wild-rye	2	1	5.0	28.3	42.5	42.5	85.0	36.3	5

*Grazed by yearling Hereford steers in 1941 from May 28 to July 30; 1942, May 16 to June 30; 1943, May 11 to July 30.

Table 4 shows the relatively high palatability of all warm-season grasses studied except that of buffalograss, when grazing was started not later than July 7. The high intensity of grazing rapidly reduced the amount of forage. Practically all the grasses had been cleaned up within a period of 22 days. Buffalograss strains from North Dakota and Kansas were scarcely touched in any of the trials. This does not imply that this species would not be eaten if cattle were confined to it, but in these trials where selection was possible it was not grazed to any extent. If the steers had remained on the rows for a longer period of time, the amount of buffalograss eaten would have been much higher because of the lack of other forage. Big bluestem must be considered the most palatable of all species tested, followed by closely grazed sandhill bluestem and little bluestem. Side-oats grama and switchgrass were eaten readily; but blue grama, which is the most important Northern Plains native grass, was not highly preferred. Sand reedgrass, which is very harsh and tough, was eaten to quite an extent.

Warm-season grasses were, in general, more highly relished than cool-season grasses. The steers would always leave young growth of cool-season grasses to graze most of the warm-season grasses immediately upon opening rows or plots of the latter to grazing.

In 1942 grazing was delayed on the warm-season rows until August 10, when most species were near or slightly past maturity. Table 5 shows that under these conditions marked differences in the order of preference were apparent from those observed when the same species were grazed early in the season. Big bluestem remained high in palatibility; other species dropped rapidly. Little bluestem, which was highly prefered in early grazing, dropped to almost a complete lack of palatability when near maturity. This species is rated low in

TABLE 4.—*Relative palatability of various warm-season grasses in rows during three periods of grazing and seasonal average, 1940, 1941, and 1943.**

Grass	No. of rows	No. of strains	Three-year average percentage of foliage removed by grazing after			Average of individual estimates of foliage removed, %	Average order of forage use	Rating based on 80 for bromegrass	Rating based on 80 for big bluestem
			5 days	12 days	22 days				
Big bluestem	4	2	81.3	100.0	100.0	86.7	1	100	80
Sandhill bluestem	2	1	78.8	95.0	95.0	84.2	2	90	80
Little bluestem	2	1	77.8	85.0	95.0	82.5	2	90	80
Side-oats grama	2	1	75.0	80.0	85.0	77.5	3	90	70
Switchgrass	6	3	73.3	81.7	86.7	76.9	3	90	70
Blue grama	2	1	50.0	85.0	90.0	62.5	4	70	60
Sand reed	2	1	56.3	60.0	70.0	59.2	5	70	50
Buffalograss	4	2	1.7	5.0	30.0	8.0	6	10	10

*Grazed by yearling Hereford steers from June 28 to July 20, 1940; May 28 to July 30, 1941; July 7 to July 30, 1943.

TABLE 5.—*Relative palatability of various warm-season grasses in rows from August 10 to 25, 1942.*

Grass	No. of rows	No. of strains	Average height Aug. 10, in.	Maturity Aug. 10	Average percentage foliage removed by grazing after			Average of individual estimates of foliage removed, %	Average order of preference
					5 days	10 days	15 days		
Big bluestem	4	2	42	Flowering	70.0	80.0	90.0	80.0	1
Switchgrass	6	3	24	Milk stage	20.0	46.7	56.7	41.1	2
Sandhill bluestem	2	1	42	Flowering	5.0	30.0	45.0	26.7	3
Side-oats grama	2	1	24	Headed	5.0	20.0	30.0	18.3	4
Sand reedgrass	2	1	48	Headed	2.0	20.0	20.0	14.0	5
Blue grama	2	1	7	Milk stage	2.0	5.0	10.0	5.7	6
Little bluestem	2	1	32	Flowering	Trace	5.0	5.0	3.3	7
Buffalograss	4	2	5	———	0	Trace	2.5	0.8	8

palatability by range men in the Northern Plains and high in the bluestem grazing section of Nebraska and Kansas. In the Northern Plains this species is confined to gravelly outcroppings on the points of hills where it is not readily available to cattle. Since it is not grazed early in the spring, cattle refuse to eat it later, even when forage becomes limited.

RELATIVE PALATABILITY OF WARM-SEASON AND COOL-SEASON GRASSES GRAZED TOGETHER AT MIDSEASON

In 1938 and 1939 plots of both warm-season and cool-season grasses were grazed from July 12 to 18 at a high intensity. As shown in Table 6, the cool-season grasses were then mature or past maturity. Warm-season grasses were in general much higher in preference than the mature cool-season grasses, except that Russian wild-rye was rather high in preference and rated above blue grama and sand reedgrass. Four cool-season grasses were preferred to this latter species. Of the cool-season grasses, bromegrass was second to Russian wild-rye and much higher than crested wheatgrass. Both the Fairway and Standard strains of crested wheatgrass were scarcely grazed when mature and

TABLE 6.—*Relative palatability of various cool-season and warm-season grasses in solid plots grazed from July 12 to 18, 1938 and 1939.**

Grass	No. of plots	No. of strains	Vegetative condition	Two-year average percentage of foliage removed by grazing after		Average of individual estimates of foliage removed, %	Average order of preference
				2 days	7 days		
Big bluestem...	3	2	Young	83.3	85.8	84.6	1
Little bluestem	1	1	Young	80.0	85.0	82.5	1
Weeping lovegrass†.......	1	1	Young	70.0	80.0	75.0	2
Switchgrass....	4	2	Young	68.8	69.2	68.9	3
Russian wild-rye	2	1	Past maturity	60.0	65.0	62.1	4
Blue grama.....	4	3	Flowering	59.3	62.9	61.1	4
Bromegrass....	2	1	Mature	52.5	55.0	53.8	5
Feather bunchgrass........	3	2	Past maturity	40.0	56.0	47.7	6
Western wheatgrass........	4	3	Coarse	22.5	52.9	36.7	7
Sand reedgrass	1	1	Young	27.5	50.0	35.0	7
Indian ricegrass	1	1	Mature	5.0	40.0	22.5	8
Slender wheatgrass........	1	1	Mature	5.0	37.5	21.3	8
Canada wild-rye	1	1	Headed	2.5	30.0	16.3	9
Fairway crested wheatgrass...	1	1	Mature	0.0	17.5	8.8	10
Standard crested wheatgrass...	7	6	Mature	0.0	12.0	6.7	10
Reed canary....	2	1	Past maturity	7.0	7.0	7.0	10

*Plots 1 rod square.
†Data for 1938 only.

ranked only slightly above reed canary. From the data presented it would be expected that in mixtures of most cool- and warm-season grasses, if grazing was delayed in the spring, the warm-season grasses would be most heavily grazed. Under a system of rotation grazing such a condition might exist, and the relative palatability of more or less mature grasses would then be important.

DISCUSSION

Some investigators have suggested that palatability is influenced primarily by the mechanical condition of the plant and that taste is not a factor. Evidence presented in this paper would suggest that taste is very important in determining the preference of cattle for certain species. In fact, taste differences were so marked between species that a number of individual persons could readily detect the wide extremes in preference by chewing a few leaves. These differences in taste, however, may not be the same with cattle. In many cases the steers preferred coarse-appearing grasses near maturity to others that had young and succulent growth. On the other hand, palatability within any one species often declined with advancing maturity. This was most striking with Standard crested wheatgrass, which is highly palatable when young but grazed only sparsely when mature.

The best management of mixed pastures should be based on the amount the most preferred species is used, if that species is to be maintained in the mixture. When cattle are first turned onto a pasture the preferred species will be closely grazed. As the season advances those grasses that are less palatable become more prevalent and those most palatable less prevalent. When this occurs, the diet then changes to less palatable species. Superficial observations on the grazing of grass by cattle may therefore lead to erroneous conclusions.

Many factors may affect palatability. Among these are:

1. *Maturity of forage.*—New growth is in general more palatable than old mature forage.

2. *Intensity of grazing.*—Heavy intensities will eventually increase the hunger of the animals to a point where previously ignored species will be readily eaten.

3. *Rate of recovery.*—Species having the ability to recover rapidly after defoliation will be preferred.

4. *Amount in mixture with associated species.*—Small amounts of less palatable species may be eaten along with associated palatable species. If those that are less preferred make up a high percentage, they may not be fully utilized.

5. *Drought resistance.*—Grasses with the ability to stay green under dry conditions will be preferred to those that readily dry up.

6. *Previous feed or grazing activity.*—Cattle may tend to graze more readily species they have previously eaten, but in case of a one-grass diet they may prefer other grasses to a continuance of the same grass.

7. *Individual differences in animals.*—Certain steers seem to eat mature crested wheatgrass and make good gains, while others will eat very little of it and do not gain.

8. *Fertilizers.*—Under conditions where nitrogen is deficient, grass on nitrogen-treated plots is generally preferred to that on nontreated plots.

9. *Kind of stock.*—Cattle, horses, sheep, or goats naturally have different preferences.

10. *Local conditions.*—Factors such as fertility, soil moisture, and available sunlight all influence palatability.

SUMMARY

Investigations undertaken in the experiment were for the purpose of determining relative palatabilities and seasonal use of various species and strains of grasses as a guide in the proper compounding of mixtures and their management.

Bromegrass was preferred to all other species of cool-season grasses under early and continuous grazing.

Fairway crested wheatgrass was much less palatable than strains of Standard crested wheatgrass under early grazing.

Russian wild-rye was low in palatability in the early season but was preferred later.

Big bluestem was the most palatable species tested. Little bluestem was palatable in the early season but was avoided when it became mature.

Buffalograss was the last species to be eaten of the warm-season group.

Mature crested wheatgrass was low in palatability and did not rate above reed canary.

LITERATURE CITED

1. ARCHIBALD, J. G., BENNETT, E., and RITCHIE, W. S. The composition and palatability of some common grasses. Jour. Agr. Res., 66:341–347. 1943.
2. BEAUMONT, A. B., STITT, R. E., and SNELL, R. S. Some factors affecting the palatability of pasture plants. Jour. Amer. Soc. Agron., 25:123–128. 1933.
3. BENDER, C. B. Five years' results of pasture fertilization and rotation management. N. J. Agr. Exp. Sta. Bul. 564. 1934.
4. DAVIES, W. The relative palatability of pasture plants. Jour. Min. Agr., 32: 106–116. 1925.
5. ROGLER, GEORGE A. Response of geographical strains of grasses to low temperatures. Jour. Amer. Soc. Agron., 35:547–559. 1943.
6. SARVIS, J. T. Grazing Investigations on the northern Great Plains. N. Dak. Agr. Exp. Sta. Bul. 308. 1941.
7. STODDART, L. A., and SMITH, A. D. Range Management. New York: McGraw-Hill Book Co. 1943.
8. WHITE, P. J., ROBERTS, I. P., and WARREN, G. F. Pastures in New York. Cornell Univ. Agr. Exp. Sta. Bul. 280. 1910.
9. WILKINS, F. S., and HUGHES, H. D. Agronomic trials with reed canary grass. Jour. Amer. Soc. Agron., 24:18–28. 1932.

INHERITANCE OF REACTION TO PHYSIOLOGIC RACES OF *CERCOSPORA ORYZAE* IN RICE[1]

N. E. Jodon, T. C. Ryker, and S. J. P. Chilton[2]

PREVIOUS investigations by Ryker and Jodon (7)[3] on the inheritance of resistance to *Cercospora oryzae* (Miyake), "Cercospora leaf spot" or "narrow brown leaf spot", in rice have shown that resistance is controlled by single dominant factors. Adair (1) also reported that in some crosses resistance is due to single dominant factors, in others to two complementary factors, and in two crosses susceptibility was dominant. His work was complicated, however, by the presence of a physiological discoloration which masked the Cercospora lesions and which could be confused with them. Some trouble of this nature was encountered at Crowley in 1942 in the present study. Also, Adair's method of classification differed from that used by Ryker and Jodon (7).

More recently, five distinct physiologic races (races 1 to 5) of *Cercospora oryzae* have been established by Ryker (5) by their differential pathogenicity on the commercial varieties Blue Rose, Blue Rose 41, Caloro, Fortuna, and "Southern Red Rice". Data including different but linked factors for resistance to races 1 and 2 were reported by Ryker and Chilton (6).

This paper summarizes data for segregations obtained in F_2 and F_3 populations, from crosses between resistant, moderately resistant, and susceptible varieties, grown in 1940, 1941, 1942, and 1943 at Baton Rouge and Crowley, La., and at Beaumont, Tex.[4]

MATERIALS AND METHODS

Crosses were made by the hot-water method previously described by Jodon (3). Parents included standard commercial varieties, pure-line introductions, and hybrid selections. The crosses were made for improvement purposes and for inheritance studies. Most of the F_1 plants were grown in the field at Crowley and Beaumont, although a few were grown in the greenhouse at Baton Rouge. The F_1 plants were not bagged as very little natural crossing occurs in rice (2).

The F_2 and F_3 plants were grown in crocks in the greenhouse at Baton Rouge or in the field at Crowley and Beaumont. All F_2 plants grown in the field were space planted, but some of the F_3 progenies were not. The plants grown at Baton Rouge were inoculated with races 1, 2, 3, or 4, either (a) by spraying with a spore suspension and holding them in a moist chamber, after which they were placed outdoors, or (b) by placing outdoors and spraying with a spore suspension at dusk. Field-grown plants were sprayed at sundown in June and July and thus tested prior to the widespread appearance of natural infection. Data from four F_2 populations which were naturally infected with race 1 also are included.

[1]Joint contribution from the Louisiana Agricultural Experiment Station, Baton Rouge, La., and the Division of Cereal Crops and Diseases, Bureau of Plant Industry, Soils, and Agricultural Engineering, Agricultural Research Administration, U. S. Dept. of Agriculture, cooperating. Received for publication December 6, 1943.

[2]Associate Agronomist, Division of Cereal Crops and Diseases, U. S. Dept. of Agriculture and Assistant Plant Pathologists, Louisiana Agricultural Experiment Station, respectively.

[3]Numbers in parenthesis refer to "Literature Cited", p. 507.

[4]The writers are indebted to H. M. Beachell, Division of Cereal Crops and Diseases, for making certain crosses and growing F_2 populations at Beaumont, Tex.

The classification of susceptible, resistant, and moderately resistant plants was the same as that used by Ryker (5), i.e., "On a plant susceptible to a culture, the spots appeared in 10 to 12 days and slowly enlarged until they were 7 to 10 mm long. On a resistant plant the lesions usually did not appear before the 18th day, and remained quite small. An intermediate reaction was observed with some varieties when inoculated with certain cultures; on these varieties, which are being considered as moderately resistant, the incubation period was 2 to 3 days longer than in the case of susceptible plants. The spots never exceeded ½ to ⅔ the length of the lesions on susceptible plants."

In 1940, at Crowley, a flood completely submerged the plants for several days, and many of the F_2 plants were killed. Data were taken before the flood, but in two crosses some susceptible plants apparently had not had sufficient time to show infection, so data were obtained on surviving plants in these crosses later in the season.

In previous studies on the mode of inheritance of resistance to *Cercospora oryzae*, only a few crosses were used, hence it seemed desirable to extend the investigations by using a larger number of crosses between parents known to be resistant or moderately resistant to the physiologic races that have been recently established. When populations of a given cross were grown at more than one station, or in more than one year, and the agreement expected for each was satisfactory, the data were combined.

All F_1 reactions tested by inoculation were like those of the resistant parents, and the segregation ratios obtained showed resistance to be dominant.

EXPERIMENTAL RESULTS

In the 48 crosses studied, the data are tabulated and discussed under single and duplicate factor ratios. In Table 1 the F_2 segregations are classed as resistant and susceptible, with a footnote for the moderately resistant class.

SINGLE FACTOR SEGREGATIONS

In 35 crosses, involving 56 populations, with a total of 14,194 plants, a single factor segregation for resistance is indicated (Table 1). Chi square, however, is so high in 11 of the 56 populations grown as to indicate poor agreement with a 3:1 ratio. Only in the cross C.I. 2474 (Res.) × Colusa (Susc.), grown at Crowley, was this due to an excess of susceptible plants. However, another population of this cross grown at Baton Rouge segregated in good agreement with the expected 3:1 ratio. The 10 remaining significant deviations from the expected are due to deficiencies in the susceptible class, indicating failure of inoculation to cause infection in all susceptible plants. Of these 10 populations, moreover, 7 were matched by one or more from the same cross which gave satisfactory agreement with the expected. In no instance where two or more populations of a cross were tested was more than one in poor agreement with the expected 3:1 ratio.

Among the totals for all crosses inoculated with each of physiologic races 1, 2, and 3, those for races 1 and 2 showed satisfactory agreement with the expected 3:1 ratio. In order to test the accuracy of the F_2 classification, in 10 crosses inoculated with appropriate races, F_3 progenies of plants classified as resistant in F_2 were grown. Sufficient lines proved to be susceptible so that the corrected F_2 results were well within the limits of the expected. Data for the resistant vs. segregating F_3 lines are presented in Table 2. In 9 of the 10 crosses, segregation was in good agreement with the expected on the basis of a 1:2 ratio. The total numbers were 154 resistant: 306 segregating lines,

compared to the expected 153:307. Apparently inoculations were less successful with race 3 than with races 1 and 2.

In the crosses C.I. 2075 (Mod. Res.) × Honduras (Res.) and C.I. 2075 (Mod. Res.) × Colusa (Res.), listed in Table 1, it was difficult to classify many of the F_2 plants because of the intermediate size of the spots on some of the resistant plants. In the cross Blue Rose (Susc.) × 323A8-32(Mod. Res.), the moderately resistant parent, unlike other moderately resistant varieties used, had a long incubation period, but eventually the lesions were as large on the resistant as on the susceptible plants, and in both populations grown the susceptible class was larger than expected.

INTERACTION OF FACTORS FOR RESISTANCE AND MODERATE RESISTANCE

The presence of both resistant and moderately resistant segregates as occurred in the cross Blue Rose (Susc.) × Rexoro (Res.), not tabulated, also made classification difficult. Moderately resistant plants, especially if the longer incubation period is not considered, are likely to be classified as susceptible. In a small population of Blue Rose × Rexoro grown at Baton Rouge and inoculated with race 1, there were 91 resistant, 16 moderately resistant, and 5 susceptible plants. This suggests the action of two factors, one for resistance and one for moderate resistance, giving a 12:3:1 ratio. (Chi^2 is 2.971 and P is between 0.50 – 0.30.)

To test this, 120 small populations of the backcross Rexoro (Res.) × Blue Rose (Susc.) – Rexoro (Res.) were grown in the field at Crowley and inoculated with race 1. On the basis of two factors of unequal value for resistance, a backcross ratio of 2 resistant, 1 segregating resistant vs. moderately resistant, and 1 segregating like the F_2 of Blue Rose × Rexoro is expected. Only those F_2 plants clearly showing resistant and susceptible reactions were classified as segregating. Assuming that most of those belonging in the second class were placed in the all resistant class because of low infection, the observed counts of 85 resistant and 35 segregating, agree fairly well with the expected numbers, 90:30.

MULTIPLE FACTOR SEGREGATIONS

In six crosses, represented by 12 populations, there were so few susceptible plants as to indicate the action of multiple factors for resistance vs. susceptibility (Table 3). Thus, in about one-sixth of the crosses studied, resistance was apparently controlled by duplicate factors. One cross, 2914A15-1-2 (Susc.) × AL 11-1 (Res.), is listed under both 15:1 and 63:1 ratios. This may have been due to the escape of susceptible plants or possibly to genetic differences, for the different families of this cross were used and the parental strains were of recent hybrid origin, and, therefore, they may have carried different factors for resistance. Virescent (Susc.) × C.I. 4630 (Res.), listed in Table 1, was as nearly in agreement with a 15:1 as a 3:1 ratio.

In the cross Virescent (Susc.) × Purple Leaf (Res.) for one population listed in Table 3, Chi^2 was so high as to indicate poor agreement

TABLE 1.—*Single factor segregations in F_2 populations for resistance and susceptibility to physiologic races 1 to 4 of Cercospora oryzae in 35 rice crosses.*

Cross*	Grown at	Year	F_1 reaction	F_2 segregation		Chi² (3:1)†
				Resistant	Susceptible	
	Race 1, Artificial Inoculation					
C.I. 4966 (Res.) ×Carolina Gold (Susc.)	Crowley, La.	1940	Res.	547	189	0.181
Carolina Gold (Susc.) ×C.I. 654 (Res.)	Crowley, La.	1940	Res.	271	90	0.001
C.I. 654 (Res.) ×Blue Rose (Susc.)	Crowley, La.	1940 & '41	Res.	429	160	1.472
C.I. 654 (Res.) ×Blue Rose (Susc.)	Crowley, La.	1942	Res.	353	59	25.061
283A10-1-1-3 (Susc.) ×AL 11-1 (Res.)	Crowley, La.	1940 & '41	Res.	391	141	0.642
C.I. 4440 (Res. ×283A10–1-1-3 (Susc.)	Crowley, La.	1941	Res.	172	70	1.989
C.I. 4440 (Res.) ×Delitus (Susc.)	Crowley and Baton Rouge, La.	1941	—	315	101	0.115
AL 11-1 (Res.) ×2913A5-1-3 (Susc.)	Baton Rouge, La.	1940	—	112	24	3.922
Caloro (Res.) ×Blue Rose (Susc.)	Baton Rouge, La.	1940	—	26	8	0.39
C.I. 461 (Res.) ×Blue Rose (Susc.)	Crowley and Baton Rouge, La.	1941	Res.	355	128	0.580
C.I. 461 (Res.) ×Early Prolific (Susc.)	Crowley, La.	1941	—	137	38	1.008
Virescent (Susc.) ×C.I. 4211 (Res.)	Crowley, La.	1940	—	411	110	4.198
Virescent (Susc.) ×C.I. 4211 (Res.)	Crowley and Baton Rouge, La.	1941	—	412	140	0.39
Virescent (Susc.) ×C.I. 4630 (Res.)	Crowley, La.	1941	—	265	40	22.978
C.I. 2474 (Res.) ×Colusa (Susc.)	Crowley, La.	1941	Res.	129	63	6.250
C.I. 2474 (Res.) ×Colusa (Susc.)	Baton Rouge, La.	1941	Res.	103	30	0.424
C.I. 2075 (Mod. Res.) ×Honduras (Susc.)	Crowley, La.	1940	Mod. Res.	87‡	30	0.026
C.I. 2075 (Mod. Res.) ×Colusa (Susc.)	Baton Rouge, La.	1941	—	159‡	54	0.14
C.I. 2075 (Mod. Res.) ×Colusa (Susc.)	Crowley, La.	1941	Mod. Res.	440‡	101	11.564
Blue Rose (Susc.) ×323A8-32 (Mod. Res.)	Crowley and Baton Rouge, La.	1940 & '41	Mod. Res.	373‡	135	0.672

Natural Infection, Probably Race 1						
Blue Rose (Susc.)×323A8-32 (Mod. Res.)	Crowley, La.	1942	Mod. Res.	87‡	41	3.375
Blue Rose 41 (Res.)×Early Prolific (Susc.)	Beaumont, Tex.	1941	—	113	46	1.310
Blue Rose 41 (Res.)×Blue Rose (Susc.)	Beaumont, Tex.	1941	—	39	13	0.000
Blue Rose 41 (Res.)×Colusa (Susc.)	Beaumont, Tex.	1941	—	45	21	1.636
Total for race 1				5,771	1,832	3.316
Race 2, Artificial Inoculation						
2918A36-2 (Susc.)×AL11-1 (Res.)	Crowley, La.	1940	—	228	60	2.667
Blue Rose sel. 2854-5-1 (Susc.)×Supreme Blue Rose (Mod. Res.)	Crowley, La.	1940	—	40‡	17	0.708
2912A13 (Res.)×Blue Rose 41 (Susc.)	Beaumont, Tex.	1941	—	168	40	3.692
2912A13 (Res.)×Blue Rose 41 (Susc.)	Beaumont, Tex.	1942	—	352	135	1.923
2912A47 (Res.)×Blue Rose 41 (Susc.)	Beaumont, Tex.	1941	—	74	28	0.327
2912A47 (Res.)×Blue Rose 41 (Susc.)	Beaumont, Tex.	1942	—	379	95	6.213
Blue Rose 41 (Susc.)×2913A29-1 (Res.)	Beaumont, Tex.	1942	—	97	27	0.688
Total for race 2				1,338	402	3.337

*C.I. numbers refer to accession numbers of the Division of Cereal Crops and Diseases. All other numbers, except Blue Rose 41, are pedigree numbers of pure line selections from crosses. Named varieties are either commercial varieties or genetic strains.

†Where Chi^2 is less than 3.841, P exceeds the 5% point.

‡Moderately resistant.

TABLE 1.—*Concluded.*

Cross*	Grown at	Year	F_1 reaction	F_2 segregation		Chi² (3:1)†
				Resistant	Susceptible	
Race 3, Artificial Inoculation						
C.I. 461 (Res.) × Caloro (Susc.)	Crowley and Baton Rouge, La.	1940	Res.	269	84	0.273
AL11-1 (Res.) × 2913A5-1-3 (Susc.)	Baton Rouge, La.	1940	—	110	26	2.510
AL11-1 (Res.) × 2913A5-1-3 (Susc.)	Crowley, La.	1940	—	346	90	4.416
Carolina Gold (Susc.) × C.I. 4966 (Res.)	Crowley, La.	1940	—	438	141	1.295
Blue Rose 41 (Res.) × Caloro (Susc.)	Beaumont, Tex.	1941	—	21	6	0.111
2913A24-1 (Susc.) × AL11-2-3-1 (Res.)	Crowley, La.	1942	Res.	239	69	1.108
2913A24-1 (Susc.) × AL5-30 (Res.)	Crowley, La.	1942	Res.	240	80	0.000
2913A24-1 (Susc.) × AL5-30 (Res.)	Crowley, La.	1942	Res.	233	67	1.138
2913A24-1 (Susc.) × AL5-30 (Res.)	Crowley, La.	1942	Res.	221	76	.055
2913A24-1 (Susc.) × AL5-30 (Res.)	Crowley, La.	1942	Res.	241	41	16.898
2913A24-1 (Susc.) × 2-20-26 (Res.)	Crowley, La.	1942	Res.	81	32	0.664
2913A24-1 (Susc.) × 2-20-26 (Res.)	Crowley, La.	1942	Res.	163	51	0.156
2913A24-1 (Susc.) × 2-20-26 (Res.)	Crowley, La.	1942	Res.	179	50	1.224
2913A24-1 (Susc.) × 2-20-26 (Res.)	Crowley, La.	1942	Res.	161	50	0.191
2913A24-1 (Susc.) × 322A6-18 (Res.)	Crowley, La.	1942	Res.	157	32	6.563
2913A24-1 (Susc.) × 322A6-18 (Res.)	Crowley, La.	1942	Res.	249	70	1.589
2913A24-1 (Susc.) × Nira (Res.)	Crowley, La.	1942	Res.	274	47	18.369
Total for race 3				3,622	1,012	24.701
Race 4, Artificial Inoculation						
Fortuna (Susc.) × C.I. 461 (Res.)	Crowley, La.	1941	Res.	158	59	0.555
Total for all races				10,889	3,305	22.279

*C. I. numbers refer to accession numbers of the Division of Cereal Crops and Diseases. All other numbers, except Blue Rose 41, are pedigree numbers of pure line selections from crosses. Named varieties are either commercial varieties or genetic strains.

†Where Chi² is less than 3.841, P exceeds the 5% point.

with the expected. This was matched, however, by another population of the same cross for which the fit for a 15:1 ratio was satisfactory. There tended to be an excess rather than a deficiency of susceptible segregates in crosses listed as segregating in a ratio of 15:1. Except in one cross, plants were inoculated with the widespread race 1, and natural infection possibly supplemented inoculation.

TABLE 2.—*F_3 tests of resistant F_2 plants from 10 crosses inoculated with physiologic races 1, 2, or 3 of Cercospora oryzae.*

Cross	Race	Number of F_3 line		Chi^2 (1:2)
		Resistant	Segregating	
Caloro × Blue Rose	1	8	17	0.020
C.I. 654 × Blue Rose	1	8	16	0.000
Blue Rose × Delitus	2	7	17	0.188
2912A47 × Blue Rose 41	2	7	11	0.250
(Stormproof × Spain Jap) × Blue Rose 41	2	12	17	0.845
Blue Rose 41 × Caloro	3	9	17	0.019
Caloro × C.I. 461	3	20	17	7.149
2913A24-1 × AL 5-30	3	27	57	0.054
291A24-1 × 322A6-18	3	20	60	2.500
2913A24-1 × Nira	3	36	77	0.111
Total		154	306	0.004

Data were obtained in the F_3 on two crosses which in F_2 gave duplicate factor segregation. The F_3 reaction of 84 F_2-resistant lines from one of these crosses, C.I. 1239 (Res.) × Early Prolific (Susc.), inoculated with race 1 at Crowley, is given in Table 4. There were fewer segregating F_3 lines than would be expected on the basis of a 15:1 or a 3:1 ratio, but Chi^2 (5.321) indicates a fair agreement with the expected 7:4:4 ratio. Of the 16 F_3 families segregating 15:1, a total of 294 plants were resistant and 25 susceptible. Chi^2 is 1.371, indicating good agreement with the expected. Of the 19 F_3 families segregating 3:1, a total of 311 plants were resistant and 93 susceptible. Good agreement with the expected is indicated by a Chi^2 of 0.845. These numbers appear to be in accord with the expected on the basis of duplicate factors.

Five crosses in which susceptibility was to races 1, 3, and 4, segregated in 63:1 ratios, and in these the number of susceptible segregates tended to be low (Table 3).

Fortuna (Susc.) × C.I. 3794 (Res.), which gave an F_2 segregation in good agreement with a 63:1 ratio, was tested in F_3 progeny rows. Rows with less than 10 plants were discarded, leaving 158 lines, whereas the F_2 population was 199 plants. There were 151 resistant and segregating vs. 7 susceptible, which agrees well with the expected on the basis of a 15:1 ratio (Chi^2 = .085). When the following classes resistant or segregating 63:1, segregating 15:1, and segregating 3:1, were compared with the expected on the basis of 15:1 (7:4:4) and 63:1 (45:12:6) ratios, however, the agreement with the expected was better for the latter, indicating that the F_2 results are correct.

TABLE 3.—*Multiple factor segregations for resistance and susceptibility to physiologic races 1, 3, and 4 in 11 crosses.*

Cross	Grown at	Year	F_1 reaction	F_2 segregation		Chi²
				Resistant	Susceptible	
Race 1, Duplicate Factors, Artificial Inoculation (15:1)						
Virescent (Susc.) × Purple Leaf (Res.)	Crowley, La.	1940 & '41	—	469	36	0.665
Virescent (Susc.) × Purple Leaf (Res.)	Baton Rouge, La.	1941	—	121	14	3.912
Virescent (Susc.) × C.I. 1239 (Res.)	Crowley, La.	1941	—	173	15	0.959
C.I. 1239 (Res.) × Virescent (Susc.)	Crowley, La.	1940 & '41	Res.	628	38	0.134
C.I. 1239 (Res.) × Early Prolific (Susc.)	Crowley and Baton Rouge, La.	1940 & '41	—	626	48	0.874
C.I. 1239 (Res.) × Delitus (Susc.)	Crowley and Baton Rouge, La.	1941	—	133	10	0.135
C.I. 2474 (Res.) × Honduras (Susc.)	Crowley, La.	1942	Res.	147	9	0.062
Race 3, Duplicate Factors, Artificial Inoculation (15:1)						
2914A15-1-2 (Susc.) × AL11-1 (Res.)	Crowley, La.	1940	—	571	39	0.021
Total duplicate factors				2,868	209	1.545

Races 1 and 3, Triplicate or More Factors (63:1)						
2914A15-1-2 (Susc.)×AL11-1 (Res.)	Baton Rouge, La.	1941	—	177	0	2.810
C.I. 2474 (Res.×Acadia (Susc.)	Baton Rouge, La.	1941	—	120	0	1.905
Race 3						
C.I. 2474 (Res.)×Acadia (Susc.)	Crowley, La.	1941	—	95	0	1.508
Caloro (Susc.)×C.I. 4700 (Res.)	Crowley and Baton Rouge, La.	1940 & '41	—	766	7	2.169
Race 4						
Fortuna (Susc.)×C.I. 3794 (Res.)	Crowley, La.	1941	—	194	5	1.168
C.I. 654 (Res.)×Fortuna (Susc.)	Crowley, La.	1942	Res.	156	1	0.874
Total triplicate factors				1,508	13	4.954
Race 1, Quadruplicate or More Factors (255:1)						
Virescent (Susc.)×C.I. 5810 (Res.)	Crowley and Baton Rouge, La.	1940 & '41	Res.	1,331	2	1.976

TABLE 4.—*F_3 breeding behavior of 84 resistant F_2 segregates from the cross C.I. 1239 (Res.) × Early Prolific (Susc.).**

Classes	Observed	Expected ratio 7:4:4
Resistant	50.0	39.2
Segregating 15:1	16.0	22.4
Segregating 3:1	19.0	22.4
Total	84.0	84.0

*$Chi^2 = 5.321$; P = .10 to .05.

In a total population of 1,333 plants in the F_2 of the cross Virescent (Susc.) × C.I. 5810 (Res.) inoculated with race 1, only 2, or possibly only 1, susceptible segregates were obtained, whereas 5 were expected on the basis of a 255:1, and 1 on the basis of a 1023:1 ratio.

DISCUSSION

In these studies, the criterion for distinguishing resistant and susceptible classes was the size of the spot and length of the incubation period. Moderately resistant, except as noted, refers to an intermediate spot with a longer incubation period. Resistant plants may finally show as many spots as susceptible, indicating that factors for resistance do not necessarily reduce infection. Differences in the length of the incubation period simplified classification, for it was possible to make counts before resistant segregates showed much infection.

Where segregations were not in good agreement with the expected ratios, there was usually a deficiency in the susceptible class. This was probably due to lack of favorable conditions for infection or to too low an inoculum potential, resulting in the escape of certain plants.

Table 1 includes data on three crosses previously reported (7), namely, C.I. 461 (Res.) × Blue Rose (Susc.), C.I. 461 (Res.) × Early Prolific (Susc.), and C.I. 4440 (Res.) × 283A10-1-1-3 (Susc.). Two of these, as before, gave segregations in good agreement with a 3:1 ratio, and while C.I. 4440 (Res.) × 283A10-1-1-3 (Susc.) previously showed a deficiency of susceptibles, the family recorded in Table 1 was in good agreement with expected.

Duplicate factors as reported here might be expected on the basis of the possible secondary polyploid origin of rice (4). Moderate resistance may be due to factors for resistance of unequal value, or to closely linked modifying factors.

Some of the parents of hybrid origin may have been heterozygous for factors for Cercospora resistance, and hence in the population grown from different F_1 plants, the factors involved were not necessarily the same.

SUMMARY

Thirty-five F_2 rice crosses gave single and 13 gave duplicate factor segregations for resistance or moderate resistance vs. susceptibility when inoculated with physiologic races of *Cercospora oryzae*. Limited F_3 and backcross studies were in substantial agreement with F_2 results.

As many as three, and probably more, duplicate factors may operate for resistance to a single race. One cross segregated for resistance, moderate resistance, and susceptibility in a 12:3:1 ratio.

LITERATURE CITED

1. ADAIR, C. ROY. Inheritance in rice of reaction to *Helminthosporium oryzae* and *Cercospora oryzae*. U. S. D. A. Tech. Bul. 772. 1941.
2. BEACHELL, H. M., ADAIR, C. ROY, JODON, N. E., DAVIS, L. L., and JONES, JENKIN W. Extent of natural crossing in rice. Jour. Amer. Soc. Agron., 30:743–753. 1938.
3. JODON, N. E. Experiments on artificial hybridization of rice. Jour. Amer. Soc. Agron., 30:294–305. 1938.
4. RAMANIJAM, S. Cytogenetical studies in the Oryzae. Ann. Bot. (n.s.), 2:107–126. 1938.
5. RYKER, T. C. Physiologic specialization in *Cercospora oryzae*. Phytopath., 33:70–74. 1943.
6. ————, and CHILTON, S. J. P. Inheritance and linkage of factors for resistance to two physiologic races of *Cercospora oryzae* in rice. Jour. Amer. Soc. Agron., 34:836–840. 1942.
7. ————, and JODON, N. E. Inheritance of resistance to *Cercospora oryzae* in rice. Phytopath., 30:1041–1047. 1940.

VARIATION AND INHERITANCE OF CERTAIN CHARACTERS OF BROME GRASS, *BROMUS INERMIS* LEYSS.[1]

Y. S. TSIANG[2]

BROME grass, *Bromus inermis* Leyss., has been grown rather extensively in the northern part of the great plains and intermountain region for pasture and hay use. It is well adapted to these regions because of its high ability to resist both drought and cold. It is useful in the north central states in mixtures with alfalfa. The investigations reported in the present paper were made on methods of breeding. The primary objectives were studies of the inheritance of leaf spot infection caused primarily by *Selenophoma bromigena*, (Sacc.) Sprague and Johnson, of beta-carotene and mineral element content, and of the effects of self-fertilization on plant characters of probable importance. A study of technic of emasculation was made also.

REVIEW OF LITERATURE

Waldron (25, 26)[3] described variations in clonal lines of brome grass. Kirk (11) and Stevenson (23) gave methods used in the production of Parkland brome grass by selection of lines that had been selfed for 4 years and then recombined. Selection was practiced for a reduction in stooling and for desirable agronomic characters. Popravko (21), in Russia, concluded that mass selection based upon ecological characters was an effective method of breeding brome grass. He recognized, however, the probable value of inbreeding as an aid to the development of the most desirable strain. Self-fertility in his studies ranged from 1 to 20%. Hayes and Schmid (5) in Minnesota have found that there was sufficient self-fertility in smooth brome so that selfed seed was obtained to carry on the selfed lines desired.

A number of diseases have been observed on brome grass. Anderson, *et al.* (2), in 1926, reported bacterial blight, ergot, powdery mildew, leaf-spots, leaf-blotches, tar-spot, scald, and smut in the northwestern part of the United States. A yellow mosaic was recently found by McKinney, *et al.* (14) in Manhattan, Kans.

Leaf-spots are caused by different organisms as indicated by different workers. The one which is caused by *Selenophoma bromigena* has been very injurious in some years in Minnesota and in neighboring states. A thorough investigation upon this particular disease was made by Allison (1) in 1940. According to his estimation, losses caused by this disease ranged from a trace to 50% in fields of *B. inermis* in Minnesota. It seemed important, therefore, to determine whether resistance to this disease could be obtained by breeding.

Beta-carotene of plants has been pointed out by various workers to be the principal source of vitamin A. Atkeson, *et al.* (3) found a wide variation in carotene content between different species of grasses. Highly significant differences

---

[1]Contribution from the Division of Agronomy and Plant Genetics, University of Minnesota, St. Paul, Minn. Paper No. 2135 of the Scientific Journal Series, Minnesota Agricultural Experiment Station. Part of a thesis submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy. Received for publication December 27, 1943.

[2]Instructor. The writer wishes to express his sincere appreciation to Dr. H. K. Hayes, Chief of the Division, for his valuable advice during the progress of this study and preparation of the manuscript. Sincere thanks are also due to the late Dr. E. S. Miller of the Department of Botany, University of Minnesota, for his valuable advice in the physiological phases of this study, and to Dr. R. C. Nelson, formerly of the Division of Plant Pathology and Agricultural Botany, University of Minnesota, for his advice and help regarding the spectrographic analysis.

[3]Figures in parenthesis refer to "Literature Cited", p. 521.

in the carotene content were found by Johnson and Miller (9) between clonal lines of Parkland brome grass and of Fairway crested wheatgrass.

It has been suggested by many investigators that each of the mineral elements might have its important function in metabolic and physico-chemical processes occurring in plant cells in ways which are not at present recognized. McHargue, *et al.* (13) found variations in mineral contents between different species of grasses. Hopper and Nesbitt (8) reported that the average of nine analyses made on brome grass samples collected at blossoming time showed differences in contents of K, Na, P, Ca, Mg, and S. It seems from these studies that there are hereditary variations in the mineral content of forage grasses, and that an intensive investigation of different lines within a species is necessary in order to secure further knowledge which might be valuable in selective breeding.

A method of bulk emasculation by means of hot water was first developed by Stephens and Quinby (22) on sorghum flowers. The same method was later studied by Li, *et al.* (12) in emasculating millet flowers, but no difference in the reaction to temperature of the staminate and pistillate organs was observed. Successful results following this method, however, have been obtained by Jodon (10) in experiments with rice. He found that treatments at 40° to 44°C for 10 minutes destroyed the viability of pollen without injury to other floral organs. Treatments by cold water at 0° to about 6°C gave similar but probably less effective results.

Suneson (24) reported that anther sterility in wheat was successfully induced by chilling plants at the temperature range of 27° to 36° F for 15 to 24 hours, 1 to 5 weeks before the spikes emerged from the boot.

Domingo (4) has reported studies at Utah that were made at about the same time as the writer's on the bulk emasculation of brome grass. He found that emasculation of brome grass panicles by hot water gave more consistent results than by hot air. Hot water treatments between 45° and 49° C on more than 40 panicles a few days prior to normal anthesis reduced selfed seed set to less than one seed per panicle and permitted an average production of 52 seeds per panicle exposed to wind-blown pollen.

MATERIALS AND METHODS

The material used in the present study was made available from the grass improvement program of the Division of Agronomy and Plant Genetics, Minnesota Agricultural Experiment Station. Thirty-two clonal lines of the Parkland variety, a noncreeping type obtained from the Dominion Experimental Farms, Ottawa, Canada, and 36 types of creeping brome, selected from seed saved from an old pasture in Martin County, Minn., were used for the studies because selfed seed of these clonal lines was available.

Studies of leaf spot infection were made in a special disease nursery with the 68 clones. Seven clonal lines from 1-year-selfed progenies of Parkland and nine of 1-year-selfed progenies of creeping brome were included. These 1-year-selfed clones were selected to include some that appeared resistant to leaf spot and others that were susceptible. The tests were made in randomized blocks, with two replications, and three clonal pieces spaced 8 inches apart for each single-row plot of each clonal line.

In the Disease Garden, artificial epidemics of leaf spot were produced by brushing individual plants and clones, in the fall of 1940, with several heavily infected plants collected from different fields at University Farm, and also by spraying twice, in the fall of 1940 and in the spring of 1941, respectively, with a water suspension from a mixture of 60 mass-spore isolates of *Selenophoma bromigena* grown on potato-dextrose-agar. These isolates represented most of the extensive collections made by E. F. Darley of the Division of Plant Pathology, University of Minnesota, from Canada, North Dakota, South Dakota, and Minnesota. The inoculations were made on cloudy days with high humidity and low temperatures because such conditions are favorable for disease development (1).

One-year-selfed progenies of the 32 clones of Parkland and the 36 of creeping brome were used to study the effects of selfing. The studies were made from the second year growth from plants spaced 4 feet apart. Separate trials were made for Parkland and for the creeping type. Two sorts of plantings were made. Where sufficient seedlings were available, a randomized block trial with two replications

was planted and 15 plants were used per plot. Where insufficient seedlings of selfed lines were available to make replication desirable, a systematic arrangement was adopted. Progenies of several selfed lines were planted in a row with plants of commercial checks in every third row so that a critical comparison between the selfed and open-pollinated plants could be made. The randomized block and systematic arrangement trials of each type of brome grass were planted in duplicate. One of the trials was planted in the Disease Garden where leaf spot infection was studied under artificial epidemic conditions. The other was planted in a separate field where notes were taken on the two crops in 1941 on leaf spot infection under natural conditions and on a number of plant characters.

The characters studied in the 1-year-selfed progenies and their parental clonal lines grown in the Disease Garden included leaf spot infection, plant height, diameter of plant base, leaf width, degree of leafiness, degree of culmage, vigor of recovery, heat and drought resistance, and habit of growth. In the Agronomy nursery, beta-carotene was studied for the parental clonal lines of both types and also for the 1-year-selfed progenies of 16 lines of the Parkland type and of 8 lines of the creeping type and of a number of check plants. Mineral element content was studied for the 36 clonal lines of the creeping type. Yield notes were taken on the 1-year-selfed progenies from two cuttings made at the time of blooming in 1941. The forage yield of each line was then expressed in grams per plant on a dry basis. Previous data were made available by the Division of Agronomy and Plant Genetics on the yielding ability of the clonal lines.

Studies of leaf spot infection, leafiness, culmage, erectness of plant, and vigor of recovery after cutting were made by placing individual plants in five groups. Group 1 contained plants that excelled in the character, i.e., were most resistant to leaf spot, recovered the quickest after cutting, etc., while groups 2 to 5 showed a gradation in the character. Plant height and diameter of plant base were recorded in inches.

During the latter part of July, 1941, it was so hot and dry in Minnesota that the temperature remained above 100°F for about 2 weeks with no rainfall. It provided an excellent opportunity to study a combination of heat and drought resistance. A few clonal lines and selfed progenies showed very heavy browning and curling of the leaves, while some other lines and progenies did so in lesser degree though most of them did not show any at all. Notes were taken by scoring them from 1 (very resistant) to 5 (least resistant or highly damaged).

In determining the beta-carotene content, samples were collected from fully headed plants. Each sample consisted of 10 or more leaves from each plant, selecting the third leaf from the top of a culm and placing the leaves in a glass vial, tightly stoppered. All collections for each type of brome grass were made on the same day and immediately frozen with dry ice. These samples were then stored at −15°C until they were analyzed 4 months later.

At the time of analyses the leaf material was chopped finely and two 1-gram portions from each sample were weighed out, one for dry matter determination and the other for beta-carotene analysis. The method of beta-carotene extraction was that given by Petering, *et al.* (19, 20) and Hegsted, *et al.* (6). The concentration of beta-carotene was measured spectroscopically at the wave length of 4525Å, according to the methods described by Miller (15, 16), with some modifications. The type of instrument used for analysis was the photoelectric spectrophotometer described by Hogness, *et al.* (7). The quantity of the carotene was expressed in p.p.m. of dry matter.

Measurements of leaf widths were made for all clonal lines and some of the 1-year-selfed progenies of the Parkland type before the leaf samples were chopped and weighed for beta-carotene analysis. Ten leaves from each sample were measured at about the middle and average values obtained.

In determining the quantitative differences in mineral element content of 36 clonal lines of the creeping type, samples of the aerial portion, including culms and leaves, were collected in cloth bags. The samples were first dried in an oven at about 70°C for 1 week, and ground in a Wiley mill. The ground material was stored in sealed glass jars. Prior to analysis, the samples were again dried in the oven at about 100°C for 24 hours, and 1 gram of each sample was weighed out and ashed for 3 hours in a muffle furnace at a temperature not exceeding 450°C. The ash was then transferred to a cork-stoppered test tube and 5 cc of 3N HCl gradually added. After standing for 2 days, the solution was analyzed by the

grating spectrograph described by Nelson (17). The details of the analytic procedure have been presented by Nelson, *et al.* (18).

Studies of bulk emasculation of brome grass by means of hot water were made on selected clonal lines which had previously shown high seed setting under a bag. The first trial was conducted in the spring of 1940 in the greenhouse. The treatments were made for 5 minutes at 5° intervals from 35° to 55°C. About 2 days before normal anthesis, certain spikelets which did not show well-developed anthers were clipped off, and four panicles for each treatment were immersed in water contained in a 1-gallon thermos jug. After each treatment two of the panicles were enclosed in a parchment paper bag and the other two were left for open pollination so that a comparison could be made of the amount of seed set under a bag and in the open. The bags used were 4 by 12 inches in size and were held in place by fastening them to a bamboo cane with a string through an eyelet at the top of the bag. The bottom of the bag was tied firmly in order to close it and then tied to the cane. A small wad of cotton had first been put around these culms to prevent injury and to exclude foreign pollen from entering the bag. Four panicles which had not been water-treated were taken as check, two of which were bagged and the others were exposed.

The number of seeds set under either bagged or exposed condition for each treatment was counted and the number of florets per panicle also determined so that the percentage of seed set could be obtained. Two further experiments were carried out in the field in the summers of 1940 and 1941, respectively. The procedures adopted were about the same as used in the greenhouse, although eight panicles were used instead of four for each treatment, four bagged and four exposed. In the 1940 studies, treatments were made for 5 minutes at 2° intervals from 44° to 50°C, while in 1941, treatments were made for different durations of 1-minute intervals from 1 to 5 minutes at 47° and 48°C.

EXPERIMENTAL RESULTS

LEAF SPOT REACTION

The data on leaf spot infection given in Table 1 were obtained under artificial epidemic conditions. Each clonal line was classified on the basis of average reaction in two replications and from two cuttings. The 5% level of significance of 0.58 for the Parkland type and 0.59 for creeping brome was obtained from an analysis of variance. There was a highly significant correlation with r values of +0.68 and +0.57 for leaf spot reaction in Parkland and creeping clonal lines, respectively, for the first and second cuttings.

TABLE 1.—*Frequency distribution for leaf spot infection of clones of Parkland and creeping brome grass; one highly resistant, five heavily infected.*

No. and kind of clones	No. of clones per class of leaf spot infection				Mean infection	5% level of significance
	1	2	3	4		
Parkland type:						
32 open-pollinated lines	8	14	9	1	2.32	0.58
7 selfed progenies......	2	3	1	1	2.11	
Creeping type:						
36 open-pollinated lines	1	16	15	4	2.76	0.59
9 selfed progenies......	2	4	2	1	2.31	

The clones of plants of the commercial varieties were fairly well distributed in four infection classes and no single clone was so heavily damaged that it was placed in class 5. In the Parkland group there

were eight very resistant clones and one susceptible, while in the creeping group there was only one very resistant line and four susceptible ones. It will be noted also that the 1-year selfed progenies were likewise widely distributed for leaf spot infection as might be expected because, as previously stated, they were selected on the basis of their low and high susceptibility to leaf spot when grown in the individual plant nursery in previous years.

Leaf spot infection data were taken also on 1-year-selfed progenies of both types of brome grass grown in individual plant nurseries in the Disease Garden and under natural conditions. Fifteen plants were grown per plot with two replications. The mean results for the leaf spot infection of the selfed lines of both types tested in the randomized block trials are summarized in Table 2 in comparison with check plots of the commercial varieties. The results are based on average infection for a line in the first and second cuttings. By the analyses of variance the standard error of a difference was calculated for each trial. The mean infection value of each of the selfed lines was then compared with the mean of the commercial check variety. In summarizing the results, each inbred line was placed in the frequency table using classes of plus and minus 1, 2, 3, etc., times the standard error of a difference from the mean of the commercial check. Lines in infection classes "−3" or greater may be considered to be more resistant than the check while lines in class "+3" may be considered more susceptible.

From Table 2 it can be readily seen that in either type of brome grass there were several lines of selfed progenies showing marked superiority in leaf spot resistance to the commercial variety of their respective type, although only one line was more susceptible. This is due to the fact that susceptible plants were not usually selected for selfing or for further propagation.

Similar results were obtained when selfed lines were compared with the adjacent checks grown in the trials with systematic arrangements. Many of the selfed lines were highly resistant to leaf spot and a few were more susceptible than the check. It seems from these studies that an improvement in the leaf spot resistance can be made easily in brome grass by selection within selfed progenies.

Highly significant r values of +0.63 and +0.66 were obtained for reaction to leaf spot of 1-year-selfed progenies and their parental clonal lines with the Parkland and creeping types, respectively, grown under comparable artificial epidemic conditions. It is apparent that heritable variations in reaction to leaf spot occur in both types of brome grass. This gives further indication that selection for resistance to leaf spot will be effective.

STUDIES OF PLANT CHARACTERS

Plant height, basal diameter, degree of leafiness, degree of culmage, vigor of recovery, leaf width, and heat and drought resistance were studied on the clonal lines of both types of brome grass when grown in the clonal nursery. Highly significant F values were obtained by the analyses of variance for all the characters studied except basal diameter for either type, indicating that the clonal lines of both types dif-

TABLE 2.—*Frequency distribution for mean leaf spot reaction of 1-year-selfed lines from two cuttings of Parkland and creeping brome grass in classes of + or −1, 2, 3, etc., times the S.E.diff. from the respective commercial variety.*

Type	Epidemic condition	No. of selfed lines	Leaf spot reaction classes										Mean of check	S.E.diff.	Mean class
			−7	−5	−4	−3	−2	−1	0	+1	+2	+3			
Parkland	Natural	10	–	2	0	2	0	4	1	1	–	–	2.59	0.17	−1.90±0.64
	Artificial	8	–	–	1	1	1	2	1	2	–	–	2.81	0.21	−1.13±0.64
Creeping	Natural	20	1	0	2	6	4	4	2	0	0	1	2.78	0.17	−2.10±0.45
	Artificial	20	–	–	1	2	5	4	1	6	1	–	3.32	0.22	−1.05±0.33

fered significantly for plant height, degree of leafiness, degree of culmage, vigor of recovery after cutting, leaf width, and heat and drought resistance but not for basal diameter.

One-year-selfed progenies of both Parkland and creeping types tested in the randomized block trials and in the trials with systematic arrangement were studied for hay yield; plant height, basal diameter, degree of leafiness, degree of culmage, degree of erectness, vigor of recovery, and heat and drought resistance. Leaf width, however, was measured only on eight lines of the Parkland type and the commercial check tested in the randomized block trial. The F value obtained by the analyses of variance indicated that the selfed progenies and commercial checks of both types differed significantly for all the characters with the exception that the progenies of the creeping type did not show a significant difference for degree of leafiness.

It was observed also that the progenies of Parkland lines did not show much increase in their basal diameter from the first to the second crops, while those of creeping lines extended their bases very rapidly during this short period.

On the basis of the S.E. of a difference computed by the analyses of variance, the means of selfed progenies for different characters were compared with the means of the checks grown from commercial seed of their respective type of brome grass. The results are summarized in frequency distributions in Table 3. Lines with more desirable characters than the check were entered in the positive classes and those with less desirable ones entered in the negative classes.

Wide variations were found among the groups of selfed progenies of both Parkland and creeping brome grass for all the characters.

The selfed progenies of either type were averaged for each of these characters and expressed in percentage of the commercial check as 100 for the respective character, as listed in the last column of Table 3. The selfed progenies of the Parkland type as a group excelled the commercial check only in erectness of growth by 25.5%, and showed definite reductions in yield, basal diameter, and culmage, as indicated by 71.4%, 78.9%, and 72.3%, respectively, of the check. The selfed group as a whole did not show much difference from the check for such characters as plant height, vigor of recovery, leaf width, and leafiness, although wide variations for the first three characters were found among the selfed progenies.

In creeping brome grass, the selfed progenies as a group excelled the check in plant height and erectness of growth by 4.2% and 29.2%, respectively. Though the selfed lines, on the average, were smaller in diameter, less culmy and less vigorous in recovery than the check, some lines were equal or superior to the check for each of these characters. Reduction in yield was significant in the selfed progenies, but there were four lines almost as high yielding as the check.

The selfed progenies of 22 lines of the Parkland type and of 16 of the creeping type grown in the trials with systematic arrangement were found also to be varying very widely for such characters as hay yield, plant height, basal diameter, degree of leafiness, degree of culmage, degree of erectness, and vigor of recovery.

TABLE 3.—*Frequency distribution of means of 1-year-selfed progenies of Parkland and creeping brome grass for several characters in classes of + or −1, 2, 3, etc., times the S.E.$_{diff.}$ from the commercial variety.*

Character studied	No. of selfed lines	Classes for various characters																	Average in % of the check as 100
		−8	−7	−6	−5	−4	−3	−2	−1	0	+1	+2	+3	+4	+5	+6	+7	+8	
Parkland Brome Grass																			
Hay yield	10	–	–	–	2	5	0	2	0	0	1	–	–	–	–	–	–	–	71.4
Plant height	10	–	–	–	3	1	0	2	0	1	1	1	0	1	–	–	–	–	95.7
Basal diameter	10	–	3	0	1	2	3	0	0	0	1	–	–	–	–	–	–	–	78.9
Leafiness	10	–	–	–	–	–	1	0	3	3	3	–	–	–	–	–	–	–	91.5
Culmage	10	1	0	1	0	3	2	1	2	–	–	–	–	–	–	–	–	–	72.3
Erectness of growth	10	–	–	–	–	–	–	–	1	1	3	3	2	–	–	–	–	–	125.5
Vigor of recovery	10	–	1	0	0	1	1	0	2	2	1	2	–	–	–	–	–	–	94.5
Leaf width	8	–	–	1	0	0	0	3	1	0	1	0	1	1	–	–	–	–	97.4
Heat and drought resistance	10	–	–	–	1	0	0	0	0	5	2	2	–	–	–	–	–	–	101.2
Creeping Brome Grass																			
Hay yield	20	–	–	1	4	1	8	2	4	–	–	–	–	–	–	–	–	–	77.9
Plant height	20	–	–	–	1	0	2	0	3	2	2	2	2	2	1	1	2	–	104.2
Basal diameter	20	2	0	1	3	4	1	6	0	1	1	1	–	–	–	–	–	–	83.0
Culmage	20	–	–	1	1	0	3	4	6	2	3	–	–	–	–	–	–	–	88.3
Erectness of growth	20	–	–	–	–	–	2	1	0	1	2	3	5	2	1	1	0	2	129.2
Vigor of recovery	20	–	–	3	3	2	0	1	3	1	1	4	2	–	–	–	–	–	88.6
Heat and drought resistance	20	–	–	–	–	1	2	4	3	8	2	–	–	–	–	–	–	–	93.0

Correlation studies of plant characters were made between the selfed progenies and their parental clonal lines for the Parkland and creeping types. In the Parkland variety, the first row in Table 4 for each character consists of selfed lines that were tested under replication and the second row for the lines in systematic arrangement without replication. All of the 20 creeping inbred lines were tested in replicated trials.

TABLE 4.—*Relationship between characters of parental clonal lines and their 1-year-selfed progenies of Parkland and creeping brome grass as indicated by the computed correlation coefficients.*

Character studied	Parkland		Creeping	
	No. of lines	r	No. of lines	r
Hay yield	— 22	— +0.47*	20	+0.06
Plant height	10 22	+0.72** +0.40	20	+0.68**
Basal diameter	10 22	+0.03 +0.59**	20	+0.29
Vigor of recovery	10 22	+0.04 +0.45*	20	+0.45*
Degree of leafiness	10 22	+0.32 +0.38	20	+0.30
Degree of culmage	10 22	−0.06 −0.28	20	+0.01
Leaf width	8	+0.94**	—	—
Heat and drought resistance	— 22	— +0.20	20	+0.32

*Exceeds the 5% level of significance.
**Exceeds the 1% level of significance.

A significant correlation coefficient was found for yield between the parental clonal lines and their selfed progenies of the Parkland type. In creeping brome grass the low coefficient, r = +0.06, does not indicate any relation of selfed progenies to their parental lines. Significant correlations were obtained for plant height and vigor of recovery in both types of brome grass, and for basal diameter in the Parkland type only. The two low coefficients obtained for basal diameter and vigor of recovery in the Parkland type were probably a result of the small number of lines involved. The r values for both varieties for degree of leafiness, vigor of recovery, and heat and drought resistance were below the 5% level of significance. Leaf width was found to be a heritable character as the selfed progenies of the Parkland type were very highly correlated with their parental clonal lines.

STUDIES OF BETA-CAROTENE CONTENT

A technic study was made to determine the accuracy and efficiency of the methods used for extraction and analysis. The amount of beta-carotene lost in the analyses of five samples made in duplicate ranged from 7.3 to 9.9%, averaging 8.5%. On the basis of the loss sustained, the methods used for extraction and analysis in this experiment were considered rather satisfactory.

Highly significant differences in beta-carotene content were found by analyses of variance among 32 clonal lines of the Parkland type and among 36 of the creeping type, respectively, which were grown in two replications in 1941. The range in mean values for beta-carotene in the Parkland clones was from 110 to 178 p.p.m. and in the creeping from 97 to 177 p.p.m.

Studies of beta-carotene content were made also on 214 1-year-selfed plants from 16 clonal lines, 36 plants of the commercial variety of the Parkland type, 96 1-year-selfed plants from eight clonal lines, and 35 plants of the commercial variety of the creeping type, which were grown in the 1938–40 individual plant nursery without replication. The beta-carotene content of individual plants of Parkland brome grass ranged from 127 to 410 p.p.m. and that of the 1-year-selfed progenies of the 16 clonal lines from 58 to 464 p.p.m. In creeping brome grass, the range of beta-carotene content in individual commercial plants was 112 to 542 p.p.m. and that of the 1-year-selfed progenies of the eight clonal lines was 84 to 482 p.p.m.

The correlation coefficient between the beta-carotene of 16 parental lines and that of their 1-year-selfed progenies of Parkland brome grass was found to be $r = +0.14$ which was not significant. The correlation coefficient between the beta-carotene content of eight parental clonal lines and that of their 1-year-selfed progenies of the creeping type was $r = +0.76$. This value was in excess of r for P of 0.05.

STUDIES OF MINERAL ELEMENT CONTENT

Spectrographic analyses of the content of Ca, Cu, Fe, Mn, Mg, and K were made on 36 clonal lines of creeping brome grass grown in two replications. Quadruplicate analyses were made for each plot of each clonal line. Low F values were obtained from analyses of variance for the content of Ca, Cu, Fe, and Mn, indicating that there were no significant differences between the 36 clonal lines in their content of these four elements. Significant differences were found for Mg content of the 36 lines with ranges in mean values from 263 to 758 p.p.m. Highly significant differences were observed also among the lines for their K content, with ranges in mean values from 1,646 to 7,012 p.p.m.

INTERRELATIONSHIP STUDIES OF PLANT CHARACTERS

Studies of interrelationships of a number of characters by means of simple correlation coefficients were made with the 32 clonal lines of Parkland brome grass and with the 36 clonal lines of creeping brome grass. For leaf spot infection, heat and drought resistance, degree of leafiness, degree of culmage, and vigor of recovery after cutting, notes

were taken in classes from 1 to 5 where 1 represented the most desirable character from an agronomic standpoint. For beta-carotene content, plant height, leaf width, and yield, the data were taken in absolute values. In calculating correlations a transformation was made so that the higher values for these last four characters would give a positive correlation with other characters when there was a positive association of higher measurements for plant height, leaf width, yield or beta-carotene content, and the more desirable expression of the other characters.

The r values that exceeded the 5% or 1% level of significance are summarized here.

Parkland Brome:	
Yield and degree of culmage	+0.47**
Yield and heat and drought resistance	+0.41*
Yield and leaf spot resistance	+0.31
Heat and drought resistance and degree of culmage	+0.42*
Heat and drought resistance and degree of leafiness	+0.76**
Heat and drought resistance and leaf spot resistance	+0.72**
Heat and drought resistance and leaf width	−0.51**
Plant height and beta-carotene content	−0.36*
Creeping Brome:	
Yield and plant height	+0.47**
Vigor of recovery and leaf spot resistance	−0.37*
Degree of culmage and plant height	−0.68**
Degree of culmage and beta-carotene content	−0.34*
Degree of leafiness and heat and drought resistance	+0.44**
Degree of leafiness and leaf width	−0.35*
Leaf width and plant height	+0.51**
Leaf width and K content	+0.63**
Leaf spot resistance and Mg content	−0.35*

*Exceeds the 5% level of significance.
**Exceeds the 1% level of significance.

In studies with the Parkland lines yield was positively and significantly correlated with degree of culmage and heat and drought resistance. A positive correlation that approached the 5% level of significance was obtained for yield and leaf spot resistance. Degree of culmage, degree of leafiness, and leaf spot resistance were positively and significantly correlated with heat and drought resistance. Heat and drought resistance was significantly but negatively correlated with leaf width. Plant height and beta-carotene content were significantly and negatively associated. No important relationships were found between the other combinations of characters.

In studies with the creeping lines yield was significantly and positively correlated with plant height. Vigor of recovery was significantly and negatively correlated with leaf spot resistance. Degree of culmage was significantly and negatively correlated with plant height and beta-carotene content. Degree of leafiness was significantly and positively correlated with heat and drought resistance, but degree of leafiness and leaf width were highly and negatively associated. Leaf width was significantly and positively correlated with plant height and K content. Leaf spot resistance was significantly and negatively associated with Mg content. No significant associations were found between the other combinations of characters.

HOT WATER METHOD OF BULK EMASCULATION

Preliminary studies in the greenhouse in 1940 indicated that 5 minutes treatment with hot water at 45°C greatly reduced the percentage of seed set in either bagged panicles or in panicles exposed to open pollination, while treatment with hot water at 50°C for 5 minutes prevented the setting of seed. In field trials in 1940 seeds were produced in panicles treated at 46°C for 5 minutes, but no seed was obtained from either 48° or 50° treatments for 5 minutes. These preliminary studies furnished the basis for the more detailed studies of bulk emasculation made in the field in 1941.

In the 1941 studies presented in Table 5, the treatments were made for different durations with 1-minute intervals from 1 to 5 minutes at 47° and 48°C. With the hot water treatment at temperatures 47° for 4 minutes and 48° for 2 minutes, no seed was produced on the bagged panicles and there was a low degree of fruitfulness in the exposed ones. The treatment at 47° for 3 minutes permitted production of only 0.30% and 0.16% fruitful florets under bagged conditions and 32.77% and 29.74% under open-pollinated conditions on plants A and B, respectively. The fruitfulness after the treatment of 48°C for 1 minute was 0.53% and 0.33% under bagged conditions and 11.42% and 7.62% under open-pollinated conditions on plants A and B, respectively.

TABLE 5.—*Percentage of fruitful florets on groups of four panicles of brome grass after hot water treatment in field, 1941.**

Duration, min.	Plant A		Plant B		Plant C	
	Panicles bagged	Panicles exposed	Panicles bagged	Panicles exposed	Panicles bagged	Panicles exposed
With Water at 48°C						
5	0	0	0	0	0	0
4	0	0	0	0	0	0
3	0	0	0	0	0	0
2	0	1.73	0	0	0	0.31
1	0.53	11.42	0.33	7.62	0	11.52
With Water at 47°C						
5	0	0	0	0	0	0
4	0	0.64	0	0.59	0	1.04
3	0.30	32.77	0.16	29.74	0	17.87
2	0.96	36.01	1.25	34.26	0	33.78
1	4.19	37.51	6.49	21.14	0	23.57
Untreated	12.04	66.61	14.15	62.73	0	60.25

*Average number of florets per panicle 189.

The treatments on plant C were made on a cloudy day with high humidity, which might account for the failure of seed setting under bagged conditions.

It seems from the results obtained that water treatment at either 47°C for 3 minutes or 48°C for 1 minute was relatively satisfactory.

The method is preferable to hand emasculation as it can be done with great ease and rapidity and only simple and inexpensive equipment is required.

SUMMARY

The primary objectives were studies of the inheritance of leaf spot infection, of beta-carotene content, and of the effects of self-fertilization on plant characters of probable importance in brome grass. Clonal lines and 1-year-selfed progenies of both the Parkland and creeping types were used. A study of hot-water methods of bulk emasculation was made also.

Highly significant differences in reaction to leaf spot, *Selenophoma bromigena*, were found between clonal lines tested in a replicated nursery under artificial epidemic conditions. A considerable proportion of the 1-year-selfed lines tested in an individual plant nursery proved superior in leaf spot resistance to the commercial variety of their respective type. Highly significant r values of +0.63 and +0.66 were obtained for reaction to leaf spot of 1-year-selfed progenies and their parental clonal lines with the Parkland and creeping types, respectively, grown under comparable artificial epidemic conditions.

Studies were made of a number of agronomic characters on the clonal lines of both the Parkland and creeping types tested in a replicated nursery and also of their 1-year-selfed progenies tested in an individual plant nursery. Significant differences were found within each group for all the characters studied with only a few exceptions. Some vigorous lines were found in the selfed group which were equal or superior to the commercial check variety for each character studied.

Plant characters including yield of hay, basal diameter, vigor of recovery, and leaf width were found to be inherited in brome grass as the selfed progenies were highly correlated with their parental clonal lines.

Significant differences for heat and drought resistance were found among the clonal lines of both the Parkland and creeping types and also among their selfed progenies. The relationships for heat and drought resistance between the parental clonal lines and selfed progenies of both the Parkland and creeping types were found to be positive, but neither of the two r values calculated reached the 5% level of significance.

There were significant differences for beta-carotene content among the clonal lines of both types of brome grass. The data on individual plants of 1-year-selfed progenies showed rather wide variations within and between lines in their content of beta-carotene. Heritable variations in beta-carotene content were found in creeping brome grass as indicated by a significant r value of +0.76 obtained for the parental clonal lines and their selfed progenies.

Spectrographic analyses of content of six mineral elements were made upon 36 clonal lines of creeping brome grass. Significant differences were found only for the content of Mg and of K between these lines.

Interrelationships of plant characters were studied with clonal lines of both types of brome grass. Relationships of importance were summarized.

Treatment of panicles of brome grass with hot water at a temperature of either 47°C for 3 minutes or 48°C for 1 minute was found to be a relatively satisfactory method of bulk emasculation.

LITERATURE CITED

1. ALLISON, J. L. Studies of a leaf spot disease on *Bromus inermis*. Thesis presented for the Ph.D. degree at the University of Minnesota. 1940.
2. ANDERSON, P. J., HASKELL, R. J., MUENSCHER, W. C., WELD, C. J., WOOD, J. I., and MARTIN, G. H. Check list of diseases of economic plants in the United States. U.S.D.A. Bul. 1366. 1926.
3. ATKESON, F. W., PETERSON, W. J., and ALDOUS, A. E. Observations on the carotene content of some typical pasture plants. Jour. Dairy Sci., 20:557–562. 1937.
4. DOMINGO, W. E. Bulk emasculation and pollination of smooth brome grass, *Bromus inermis*. Jour. Amer. Soc. Agron., 33:993–1002. 1941.
5. HAYES, H. K., and SCHMID, A. R. Selection in self-pollinated lines of *Bromus inermis* Leyss., *Festuca elatior* L., and *Dactylis glomerata* L. Jour. Amer. Soc. Agron., 35:934–943. 1943.
6. HEGSTED, D. M., PORTER, J. W., and PETERSON, W. H. Determination of carotene in silage. Ind. and Eng. Chem., Anal. Ed., 11:256–258. 1939.
7. HOGNESS, T. R., ZSCHEILE, F. P., JR., and SIDWELL, A. E., JR. Photoelectric spectrophotometry. Jour. Phys. Chem., 41:379–415. 1937.
8. HOPPER, T. H., and NESBITT, L. L. The chemical composition of some North Dakota pasture and hay grasses. N. Dak. Agr. Exp. Sta. Bul. 236:28–29. 1930.
9. JOHNSON, I. J., and MILLER, E. S. Leaf pigment concentration and its relation to yield in Fairway crested wheatgrass and Parkland brome grass. Jour. Amer. Soc. Agron., 32:302–307. 1940.
10. JODON, N. E. Experiments on artificial hybridization of rice. Jour. Amer. Soc. Agron., 30:294–305. 1938.
11. KIRK, L. E. Methods employed in the breeding of biennial sweet clover (*Melilotus*) and brief notes on the breeding of lucerne (Medicago sativa), brome grass (*Bromus inermis*) and slender wheatgrass (*Agropyron tenerum*). Imp. Bur. Plant Gen., Herbage Plants Bul. 7:5–13. 1932.
12. LI, H. W., MENG, C. J., and LIU, T. N. Problems in the breeding of millet, *Setaria italica* (L.) Beauv. Jour. Amer. Soc. Agron., 27:963–970. 1935.
13. MCHARGUE, J. S., ROY, W. R., and PELPHREY, J. G. The iron, manganese, copper, zinc, and iodine content of some important forage crops. Jour. Amer. Soc. Agron., 24:562–565. 1932.
14. MCKINNEY, H. H., FELLOWS, H., and JOHNSTON, C. O. Mosaic of *Bromus inermis*. Phytopath., 32:331. 1942.
15. MILLER, E. S. A rapid and accurate quantitative method for the determination of the common carotinoids; analysis of beta-carotene and leaf xanthophyll in thirteen plant tissues. Jour. Amer. Chem Soc., 57:347–349. 1935.
16. ————. A precise method with detailed calibration for the determination of absorption coefficients; the quantitative measurement of the visible and ultra-violet absorption spectra of alpha-carotene, beta-carotene and lycopene. Plant Phys., 12:667–684. 1937.
17. NELSON, R. C. A grating spectrograph for mineral nutrition studies. Plant Phys., 17:492–496. 1942.
18. ————, HAMM, PHILIP, and TSIANG, Y. S. The spectrographic analysis of plant ash for several elements simultaneously. Plant Phys., 18:699–703. 1943.
19. PETERING, H. G., BENNE, E. J., and MORGAL, P. W. Simplification of the Petering-Wolman-Hibbard method for determination of chlorophyll and carotene. Ind. and Eng. Chem., Anal. Ed., 13:236. 1941.
20. ————, WOLMAN, W., and HIBBARD, R. P. Determination of chlorophyll and carotene in plant tissue. Ind. and Eng. Chem., Anal. Ed., 12:148–151. 1940.
21. POPRAVKO, A. V. Breeding *Bromus inermis* (Transl. title, Russian): Selek. i Semenovodstvo, 4:49–50. 1934. (Cited from Herb. Abst., 5:139. 1935.)

22. STEPHENS, J. C., and QUINBY, J. R. Bulk emasculation of sorghum flowers. Jour. Amer. Soc. Agron., 25:233–234. 1933.
23. STEVENSON, T. M. Work of the Dominion Forage Crops Laboratory, Saskatoon, Sask., in cooperation with the University of Saskatchewan. Rpt. Dom. Agrostologist, 1934–36: 20–28. 1937.
24. SUNESON, COIT A. Emasculation of wheat by chilling. Jour. Amer. Soc. Agron., 29:247–249. 1937.
25. WALDRON, L. R. Some physical and chemical studies of certain clones and sibs of brome grass. N. Dak. Agr. Exp. Sta. Res. Bul. 152. 1921.
26. ————. Physical characters and some of their correlations in *Bromus inermis*. N. Dak. Agr. Exp. Sta. Res. Bul. 153. 1921.

SEED PRODUCTION OF SEVERAL SOUTHERN GRASSES AS INFLUENCED BY BURNING AND FERTILIZATION[1]

Glenn W. Burton[2]

FOR the past 2 years the demand for southern grass seed has far exceeded the supply. Until recently, almost the entire production of carpet and Bermuda grass seed has been absorbed by the various war agencies. Many farmers have been unable to purchase seed of Dallis and Bahia grass. Grass seed has been and may well continue to be a bottle-neck in the pasture improvement program of the South unless more effective methods of increasing seed production are found and utilized.

Bahia grass and some of the other southern grasses tend to reach a peak in seed production the year after they are seeded. Seed yields decline rapidly in subsequent years and by the third or fourth year Bahia grass that has grown on good soil and has not been closely grazed produces very little seed.

Several workers, including Evans and Calder (4),[3] Evans (3) and De France and Odland (2), have studied the influence of fertilizer mixtures upon seed yields of several of the northern grasses. They agree that, generally, seed yields may be increased by moderate applications of nitrogen and that phosphorus and potassium have negligible effects upon yields of seed either alone or with nitrogen. Burton (1), studying some of the factors influencing seed setting in 10 southern grasses, found that fertilization had no significant effect upon the percentage of florets to set seed. He observed, however, that seed yields, as measured by the number of heads per unit area, were usually influenced little by applications of phosphorus and potash but were increased materially when nitrogen was added to the basic phosphorus and potash treatment.

In an experiment designed to measure the effect of fertilization upon seed setting in 10 southern grasses, fire was used each spring, beginning in 1938, to remove accumulated top growth. It was observed that some of the grasses in this test, particularly Bahia grass, continued to seed much better than usual. That fire might be responsible for these continued high seed yields became evident in the fall of 1941 when W. O. Sheppard, Junior Range Examiner, U. S. F. S. at Tifton, Ga., pointed out that such native grasses as *Aristida stricta* and *Sporobolus curtissii*, which rarely flower in old sods, flower profusely after the sod has been burned. So far as the author is aware, this reaction has not been previously described in the literature.

---

[1]Cooperative investigations at Tifton, Ga., of the Division of Forage Crops and Diseases, Bureau of Plant Industry, Soils, and Agricultural Engineering, Agricultural Research Administration, U. S. Dept. of Agriculture, the Georgia Coastal Plain Experiment Station, and the Georgia Experiment Station. Also presented at the annual meeting of the Society at Cincinnati, Ohio, Nov. 10 to 12, 1943. Received for publication January 4, 1944.

[2]Geneticist, U. S. Dept. of Agriculture, Tifton, Ga.

[3]Figures in parenthesis refer to "Literature Cited", p. 529.

MATERIALS AND METHODS

In the spring of 1942 experiments were set up to determine the effect of spring burning upon seed production on old sods of Bahia grass, *Paspalum notatum* Flügge, Bermuda grass, *Cynodon dactylon* (L.) Pers., and ribbed paspalum, *Paspalum malacophyllum* Trin. Since the plots used for these studies were uniformly burned in the spring of 1941, only one season's growth had accumulated upon them. Half of the replicated 4×4 foot plots laid out in these sods were burned on March 29, 1942. The same plots, from which only seed heads were removed in 1942, were burned again on April 15, 1943. The yields of seed (florets containing caryopses) produced per plot on burned and unburned areas were determined both years and were analyzed statistically.

In 1943 a 4-year-old sod of Paraguay Bahia grass, growing on a Tifton sandy loam, was subjected to the following treatments: Duplicate 1/90-acre plots were burned January 12, February 13, March 11, and April 15. Two unburned plots were retained as checks. On April 27 each of these plots was divided into three equal parts which received the following fertilization treatments: 1, No treatment; 2, 4-8-4 fertilizer at the rate of 1 ton per acre; and 3, nitrate of soda (16% N) at the rate of 500 pounds per acre. The influence of these treatments upon the heading date, seed yield, head size, seed weight, the percentage of florets containing caryopses, and vegetative growth was determined during the summer of 1943.

The effect of burning upon the seed yield of carpet grass, *Axonopus affinis*, and several different strains of Bahia grass was studied in 1943.

RESULTS

The effect of burning the dead top growth on sods of common Bahia grass, ribbed paspalum, and two strains of Bermuda grass in 1942 and 1943 is shown in Table 1. The fact that burned plots of common Bahia grass and both strains of Bermuda grass yielded significantly more seed than unburned plots in 1942 and 1943 indicates that burning stimulates seed production in these species. On the other hand, it appears that burning will not increase and may actually decrease the seed yield of ribbed paspalum. The percentage increase in the seed yields of Bahia grass and Bermuda grass that resulted from burning was much greater in 1943 than in 1942. This was probably due to the fact that by 1943 the unburned plots which had not been burned for 2 years were following the usual pattern of rapidly falling off in seed production. These results suggest that over a period of years these grasses will produce greater yields of seed if burned annually than if

TABLE 1.—*The effect of burning upon the seed yields of several southern grasses.*†

Species	Pounds of seed produced per acre in			
	1942		1943	
	Burned	Not burned	Burned	Not burned
Common Bahia grass.......	221	126**	101	13**
Common Bermuda grass....	46	16*	29	3**
Bermuda grass P.I. 105933	47	1**	5	0.5**
Ribbed Paspalum........	34	35	41	46

†The dead top growth was burned March 29, 1942, and April 15, 1943. The statistical significance of differences between the burned and unburned yields are marked in the usual manner.
*Exceeds P .05.
**Exceeds P .01.

burned biennially. A study of this problem is now under way at Tifton, Ga.

The response of a 4-year-old sod of Paraguay Bahia grass to fertilization and different dates of burning was carefully studied in 1943. It was observed that plots burned in January, February, and March and fertilized with N or NPK began to head on June 1, while plots burned in April and plots not burned began to head June 8. Unfertilized plots headed about a week later than fertilized plots in all of the burning treatments.

The burned plots produced many more but somewhat smaller panicles than the unburned plots. (See Fig. 1.) Any differences in panicle size that may have resulted from fertilization or date of burning were too small to be noticeable.

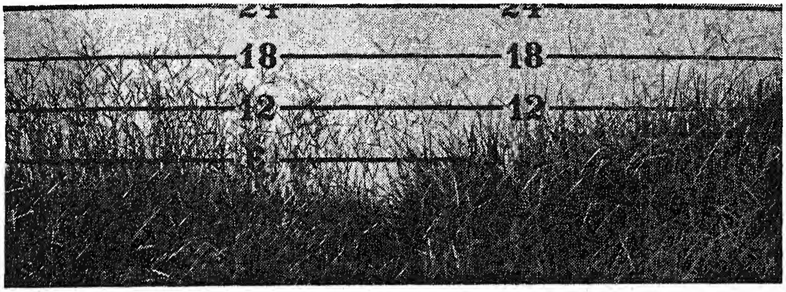


FIG. 1.—The effect of burning upon seed production in a 4-year-old sod of Paraguay Bahia grass uniformly fertilized with 500 pounds of nitrate of soda per acre. The sod left center was burned March 11, 1943. The sod right center was not burned.

Since Paraguay Bahia grass does not lose its seed by shattering, it was possible to permit the entire season's production to accumulate before harvesting the seed. The yields of seed (florets containing caryopses) harvested on August 2 are presented in Table 2 and the analyses of variance of these data appear in Table 3. It is apparent from these tables that both burning and fertilization were effective factors

TABLE 2.—*The influence of burning and fertilization upon the production of Paraguay Bahia seed in 1943.**

Burning date	Pounds of seed produced per acre when fertilized with			
	None	4-0-0	4-8-4	Average
Not burned	80	425	332	279
Jan. 12, 1943	200	731	931	621
Feb. 13, 1943	306	918	904	709
Mar. 11, 1943	399	838	918	718
Apr. 15, 1943	319	851	825	665
Average	261	753	782	596

*Fertilizer was applied at the rate of 1 ton per acre. Nitrate of soda (16% N) was the only form of nitrogen used in these fertilizers.

in increasing seed yields several fold. Fertilization of the burned plots gave the highest yields, but the percentage increase due to fertilization was greater in the unburned plots. Table 3 shows that this interaction exceeded the 5% level of significance. It is interesting to note that the date of burning had no significant effect upon seed yield and that nitrogen alone produced as much seed as an equivalent amount of nitrogen in a 4–8–4 fertilizer.

TABLE 3.—*The influence of burning and fertilization upon the production of Paraguay Bahia seed in 1943.*†

Source	D.F.	Sums of squares	Mean square
Replication	1	1.08	—
Burning vs. none	1	10.80	10.80**
Dates of burning	3	0.51	0.17
Error (a)	4	2.01	0.50
Fertilizer vs. none	1	24.19	24.19**
N vs. NPK	1	0.06	0.06
Fertilizer vs. none × burning vs. none	1	1.02	1.02*
Fertilizer vs. none × date of burning	3	0.81	0.27
N vs. NPK × burning	4	0.78	0.19
Error (b)	10	1.72	0.17
Total	29	42.98	

†Analyses of variance: pounds per plot.
*Exceeds P .05.
**Exceeds P .01.

Analyses of the florets produced upon these plots revealed that neither burning nor fertilization had any effect upon the percentage of florets to set seed. The failure of fertilization to influence seed setting in this species has been previously shown (1).

In order to determine the effect of burning and fertilization upon the weight of 100 seeds (florets containing caryopses) of Paraguay Bahia grass, duplicate 100-seed samples were taken from each lot of seed. The summary of the weights of these seeds in milligrams appears in Table 4. Statistical analyses of these data revealed that burning

TABLE 4.—*The influence of burning and fertilization upon the weight of Paraguay Bahia seed produced in 1943.**

Burning date	Weight in mgm of 100 florets containing caryopses when fertilized with			
	None	4–0–0	4–8–4	Average
Not burned	260	263	249	257
Jan. 12, 1943	240	242	233	238
Feb. 13, 1943	241	242	230	238
Mar. 11, 1943	244	241	233	239
Apr. 15, 1943	249	249	240	246
Average	247	247	237	244

*Fertilizer was applied at the rate of 1 ton per acre. Nitrate of soda (16% N) was the only form of nitrogen used in these fertilizers.

significantly reduced the weight of individual seeds and that seeds from April-burned plots were heavier than those from plots burned in January, February, and March. Since burning decreased the panicle size, it might also be expected to reduce the weight or size of individual seeds. Why April burning should produce larger florets than earlier dates of burning and why phosphate and potash, when added to the nitrogen fertilization, should have consistently and significantly reduced seed weight cannot be explained with the information now available.

On September 17, 1943, all of the 1943 aboveground growth was removed from representative quadrats within each plot in this experiment. Since the panicles and seed stalks had been removed earlier, these yields, summarized in Table 5, indicate the influence of burning and fertilization upon the vegetative growth of Paraguay Bahia grass in 1943. Analyses of the moisture content of these samples showed that the burning and fertilization treatments were exerting no influence upon the succulence of the grass at the time that these samples were taken. The striking increase in vegetative growth that resulted from the fertilization of this grass has been obtained in other experiments and was expected. Table 5 shows that the unburned plots made more vegetative growth than the burned plots in 1943. Since burning did not affect the stand of grass and since plots burned in January, February, and March started to grow before the unburned plots, variations in stand of grass or length of the growth period cannot account for these differences in vegetative yield. Table 2 shows that the burned plots produced approximately 2.5 times more seed than the unburned plots. Since the burned plots produced much smaller panicles, they must have produced 4 to 5 times as many as the unburned plots. It appears, therefore, that burning acted as a stimulus, changing the plants from a vegetative to a reproductive condition and, consequently, energy that went into vegetative growth in the unburned plots went into seed production in the burned plots.

TABLE 5.—*The influence of burning and fertilization upon the vegetative growth made by Paraguay Bahia grass during 1943.**

Burning date	Pounds per acre of dry matter (1943 vegetative growth) when fertilized with			
	None	4-0-0	4-8-4	Average
Not burned	5,800	14,500	12,600	10,967
Jan. 12, 1943	5,100	7,200	8,700	7,000
Feb. 13, 1943	5,500	11,300	9,300	8,700
Mar. 11, 1943	4,200	8,200	7,800	6,733
Apr. 15, 1943	3,800	9,200	8,800	7,267
Average	4,880	10,080	9,440	8,133

*Fertilizer was applied at the rate of 1 ton per acre. The entire season's growth of leaves and stems (panicles were previously removed) was cut September 17, 1943, for these determinations. Nitrate of soda (16% N) was the only form of nitrogen used in these fertilizers.

The following preliminary test was conducted in 1943 to determine the effect of burning upon nine different strains of Bahia grass. A

space-planted progeny test planted in 1941 was used for the test. Two of the 10 replicated blocks containing all nine strains were burned in January, February, March, and April and the remaining two were left as checks. Seed yields were determined and, in general, indicated that burning may be expected to increase the seed production of any of the strains tested. The Pensacola strain of Bahia grass, when burned in April, yielded less than when not burned, indicating that early heading strains of this type should not be burned later than the middle of March.

Duplicate 1/100-acre plots of a turf strain of Bahia grass were burned on January 12 and April 15, 1943. These plots produced 715 and 713 grams of good seed per plot, respectively, as compared with 205 grams of seed harvested from the unburned check plots. These yield differences were highly significant and indicated that burning will stimulate seed production in this strain of Bahia grass.

On April 15, 1943, five of 10 small plots laid out in an old carpet grass sod were burned. The seed yields of these plots showed that the unburned check plots produced twice as much seed as the burned plots in 1943. This difference exceeded the 1% level of significance and indicated that burning will reduce the seed yields of carpet grass. Since the the burning operation killed portions of some of the plants and noticeably reduced the stand, it is quite probable that most of the reduction in seed yield resulted from a reduction in the number of buds from which seed stalks could be formed.

DISCUSSION

It will be necessary to conduct additional research in order to explain why burning and nitrogen stimulate seed production in some grasses. Preliminary observations suggest that removing accumulated top growth by mowing or close grazing will tend to increase seed yields in much the same manner as burning but to a lesser degree. Burning and fertilization will no doubt have cumulative effects that may be considerably different from the early effects here reported. Experiments designed to measure these cumulative effects are being conducted but obviously cannot yield the desired information for some time. Many other questions such as the frequency and intensity of burning and the optimum fertilization rates, must also be determined for each species and each region. This preliminary report merely attempts to suggest that the proper use of fire and fertilizer may help to solve some of the problems now encountered in the production of perennial grass seed.

SUMMARY AND CONCLUSIONS

Burning old sods of Bahia grass and Bermuda grass stimulated seed production and resulted in greatly increased yields of seed. Burning had no effect upon the seed yield of ribbed paspalum and actually reduced the yield of carpet grass seed significantly. It is evident, therefore, that burning will not stimulate seed production in all grasses.

In Paraguay Bahia grass burning increased the head abundance, decreased the panicle size and seed weight and had no influence upon

the percentage of florets to set seed. These results, together with the decreased vegetative growth that resulted from burning dormant sods of this grass, indicate that burning changed the plants from a vegetative to a reproductive condition.

Generally, January, February, March, and April burnings were equally effective in stimulating seed production in Bahia grass. A notable exception was found in the early maturing Pensacola strain of Bahia grass which produced less seed than the unburned checks when burned in April.

The favorable response of nine different strains of Bahia grass to burning indicates that burning old sods may be expected to stimulate seed production in all strains of this species.

In 1943, the first year of this study, nitrate of soda (16% N) applied at the rate of 500 pounds per acre and 4–8–4 fertilizer at a 2,000-pound rate were equally effective in increasing the yield of seed and the aboveground parts in Paraguay Bahia grass. Fertilization of the burned plots gave the greatest seed yields, but the percentage increase, due to fertilization, was greater in the unburned plots.

LITERATURE CITED

1. BURTON, GLENN W. Factors influencing seed setting in several southern grasses. Jour. Amer. Soc. Agron., 35:465–474. 1943.
2. DE FRANCE, J. A., and ODLAND, T. E. Seed yields of velvet bent, *Agrostis canina* L., as influenced by the kind of fertilizer applied. Jour. Amer. Soc. Agron., 34:205–210. 1942.
3. EVANS, G. Technique of grass seed production at the Welsh Plant Breeding Station. Welsh Plant Breed. Sta. Bul. 22. 1937.
4. ———— and CALDER, R. A. Manuring pedigree grasses for seed production. Welsh. Jour. Agron., 7:195–208. 1931.

LENGTH, FINENESS, AND STRENGTH OF COTTON LINT AS RELATED TO HEREDITY AND ENVIRONMENT[1]

N. I. HANCOCK[2]

COTTON lint is a composite of the fibers, and as such is sampled and measured by the trade. Length is the primary measurement—the chief criterion of quality. Cotton fibers possess other important properties, but until recently no rapid and accurate methods for their measurement had been developed. The inventions by Hertel (1, 3, 4),[3] Hertel and Zervigon (2), Sullivan and Hertel (7), and Pressley (5, 6) have resulted in instruments and methods adequate for measuring rapidly the physical properties of length, fineness, and strength of cotton lint.

The measurement of fineness by the new method has not been reported for cotton varieties; nor has the possible genetic and environmental association of the three properties been discussed. It is the purpose of this paper to show the differences among varieties in their expression of length, fineness, and strength of lint, and to consider the environmental influence upon such expressions.

EXPERIMENTAL METHODS

The measurements reported in this paper were taken on samples of cotton from variety tests in Tennessee. These tests were located at Tiptonville, Lake County, in the delta of the Mississippi River, on sandy loam soil of the Sharkey series; at Jackson, Madison County, on Memphis silt loam; and at Knoxville, Knox County, on Decatur loam.

The growing seasons at these three locations the past two years were about as wide in range as those encountered during the preceding four years. The 1941 season at Knoxville and Tiptonville was an optimum growing season for cotton, whereas at Jackson it was abnormally dry. The 1942 season was a favorable one for the growth of cotton at Jackson and Tiptonville, while at Knoxville it was excessively rainy.

The same varieties were grown at all three locations in a given season. There were five replicates of each variety at each location. A 50-boll sample of seed cotton was picked from each replicate, and, in turn, a sample of lint drawn from each ginned sample.

It would require too much space to describe in detail the instruments which give the measurements on these properties. The fibrograph (1, 2, 3, 4) measures length—it draws a curve, and from this curve the mean length and the upper half mean length are obtained. The upper half mean length is very similar to the classer's length and is the one reported. The arealometer (7) measures fineness—it gives the surface area of the lint in square centimeters per milligram. The Pressley fiber strength tester (5, 6) measures strength—it gives the force in pounds required to break 1 mgm of lint in which a bundle of fibers is approximately 1.18 cm long. Personal bias is largely eliminated by these instruments. All measurements were made in an air-conditioned laboratory, with mean temperature of 70° F, and mean relative humidity of 65°.

EXPERIMENTAL RESULTS

Table 1 reveals large differences in each property among the varieties and within a single variety. For example, in 1941, Stoneville 2B

[1]Contribution from the Department of Agronomy, University of Tennessee, Knoxville, Tenn. Received for publication January 10, 1944.

[2]Associate Agronomist.

[3]Figures in parenthesis refer to "Literature Cited", p. 536.

had a range of over 3/32 in length, 0.23 in fineness, and 0.36 in strength. In 1942, Coker 100 Wilt (39–5), and other varieties, showed about the same range. Significant differences in each property are shown in samples from different locations. Cotton of all varieties, in both seasons, is shorter and stronger at Jackson than at Knoxville, or Tiptonville, and the order of these locations remains constant for each property.

TABLE 1.—*Upper half mean length, fineness, and strength of cotton lint by varieties, locations, and seasons in trials at Tiptonville, Jackson, and Knoxville, Tenn.**

Variety	Length, 32nds in.			Fineness, cm/mgm²			Strength, lbs. per mgm		
	Tipton-ville	Jackson	Knox-ville	Tipton-ville	Jackson	Knox-ville	Tipton-ville	Jackson	Knox-ville
					1941				
Washington	32.8	30.8	33.2	2.85	2.64	2.95	6.97	6.95	6.32
Stoneville 2B	33.6	31.5	35.2	2.81	2.63	2.86	6.54	6.50	5.86
Stoneville 8-66	32.6	29.3	33.2	2.82	2.65	2.88	6.56	6.57	5.84
Marett's White Gold	33.3	31.5	34.8	2.74	2.61	2.85	6.50	6.57	5.84
Stoneville 5-4-64-1	30.4	28.1	31.5	2.54	2.37	2.46	6.81	6.75	6.01
Coker 200-1	34.5	30.9	35.2	2.44	2.45	2.65	6.40	6.40	5.57
Coker 200-2	33.5	30.8	33.6	2.60	2.55	2.59	6.28	6.29	5.55
Deltapine 11A	32.4	30.7	33.8	2.51	2.35	2.61	6.16	6.47	5.42
Deltapine 12	32.3	28.9	32.5	2.81	2.60	2.79	6.12	6.13	5.37
Hibred	27.0	23.9	27.3	2.15	2.22	2.30	6.52	6.48	5.84
Means of stations	32.2	29.6	33.1	2.63	2.51	2.69	6.49	6.51	5.76
Means of seasons	—	31.7	—	—	2.61	—	—	6.25	—
					1942				
Washington	34.2	32.7	35.2	2.57	2.56	2.78	6.33	6.61	6.14
Stoneville 2B	36.0	34.3	36.0	2.62	2.52	2.76	6.17	6.48	5.89
Marett's White Gold	34.4	34.1	35.3	2.69	2.47	2.71	5.93	6.45	5.65
Bobshaw No. 1	33.4	32.9	34.6	2.27	2.25	2.44	6.19	6.78	5.93
F_2 8-66×15-612	33.2	32.6	35.2	2.64	2.45	2.75	6.42	6.95	5.94
F_2 8-66×626-9	32.4	32.1	35.1	2.62	2.43	2.72	6.17	6.26	5.62
Coker 100, Str. 6	35.3	35.1	37.5	2.64	2.57	2.77	5.63	6.15	5.75
Coker 100 Wilt (39-5)	33.5	32.6	36.0	2.35	2.27	2.57	5.61	6.13	5.40
Coker 200-Str. 2	33.6	34.3	36.7	2.35	2.27	2.43	5.59	6.07	5.50
Deltapine 14	34.8	33.2	36.2	2.42	2.53	2.53	5.50	6.25	5.64
Means of stations	34.1	33.4	35.8	2.52	2.43	2.65	5.95	6.41	5.75
Means of seasons	—	34.4	—	—	2.53	—	—	6.03	—

* Mean values of five replicates of each variable at each location.

The differences among varieties may appear small to one unfamiliar with these measurements, but in Table 2 the mean squares for error show them to be highly significant. When all the tests are combined for a given season, it is seen that location exerts a greater effect than variety upon these properties. This is due, in part, to extreme seasonal conditions at Jackson in 1941 and at Knoxville in 1942. Soil differences within a test do not affect the properties of length and fineness a great deal, as shown by the mean squares for blocks, but ap-

parently strength is sensitive to small soil differences in some of the tests.

TABLE 2.—*Variance analysis of length, fineness, and strength of lint cotton by varieties at each location and at all locations.*

Location	D.F.	Mean squares					
		1941			1942		
		Length, 32nds in.	Fineness, cm² mgm	Strength, lbs. per mgm	Length, 32nds in.	Fineness, cm² mgm	Strength, lbs. per mgm
Tiptonville:							
Blocks	4	1.332	0.069	0.048	2.404	0.002	0.179
Varieties	9	22.912	0.256	0.359	5.926	0.125	0.591
Error	36	0.989	0.017	0.061	0.701	0.015	0.049
Jackson:							
Blocks	4	1.118	0.023	0.074	1.221	0.033	0.245
Varieties	9	26.720	0.112	0.255	5.138	0.076	0.461
Error	36	1.113	0.096	0.056	0.925	0.006	0.083
Knoxville:							
Blocks	4	0.669	0.037	0.157	1.471	0.031	0.088
Varieties	9	26.540	0.221	0.419	4.021	0.095	0.302
Error	36	0.488	0.014	0.050	0.962	0.018	0.083
All locations							
Locations	2	162.220	0.4483	8.9689	74.530	0.5773	5.5435
Varieties	9	74.226	0.5417	0.9792	8.702	0.1821	0.9099
V×L (error)	18	0.973	0.0212	0.0264	3.180	0.0562	0.2223

It is shown in Table 1, however, that the varieties give strong genetic expressions of these properties. There are significant differences between the varieties. Furthermore, in any particular property, the varieties generally occupy the same order at all locations. For instance, Washington, Stoneville 8–66, Stoneville 2B, and Maretts White Gold lead in fineness at all three locations in 1941. No one group appears to be superior in all these properties. Thus, one group of varieties leads in fineness, while another group leads in strength, and still another one in length. No one variety of medium-length cotton is superior in all these properties, but Washington ranks high in fineness and strength, and is fairly long. In Table 3, Wilds 13, a very long cotton, is shown to be superior in all three properties. But Delfos 9252, a 1-3/16-inch cotton, is weaker than Stoneville 68–3, a 1-inch cotton. Bobshaw 16, a 1-1/8-inch cotton, is coarser than Stoneville 68–3.

A comparison of the environmental and genetic expressions of these properties is given in Table 4. The variences in this table are calculated from data on four varieties which were used in all the tests both seasons. These varieties are Washington, Stoneville 2B, Marett's White Gold, and Coker 200–2. In this table it is seen that locations and seasons have considerable effect on these properties. Locations affect strength more than either varieties or seasons, whereas, seasons

TABLE 3.—*Rank of varieties in upper half mean length, fineness, and strength in test at Jackson, 1942.*

Variety	Length, 32nds in.	Variety	Fineness, cm^2 mgm	Variety	Strength, lbs. per mgm
Wilds, Str. 13....	42.2	Wilds, Str. 13...	2.80	Wilds, Str. 13...	7.35
Delfos 9252.....	38.1	Delfos 9252....	2.79	Bobshaw 16....	7.02
Bobshaw 16.....	36.2	Stoneville 68-3	2.55	Stoneville 68-3	6.69
Coker 100, Str. 4	34.3	Bobshaw 16....	2.42	Coker 100, Str. 4	6.10
Stoneville 68-3..	32.0	Coker 100, Str. 4	2.39	Delfos 9252....	6.09

affect fineness and length more than varieties or locations. The interactions of either seasons × varieties or of locations × varieties show no significant differential response of the varieties with respect to these variables, and the triple interaction shows no significance. The sensitiveness of strength is shown by the significance of the mean square of blocks within locations and seasons.

TABLE 4.—*Variance analysis on length, fineness, and strength of lint cotton for four varieties, three locations, and two seasons.*

Factors	D.F.	Mean square		
		Length	Fineness	Strength
Varieties........................	3	8.92**	0.4132**	2.291**
Locations........................	2	60.68**	0.4263**	4.292**
Seasons..........................	1	101.93**	0.7776**	2.503**
Seasons × locations..............	2	6.01**	0.0099	0.601**
Seasons × varieties..............	3	0.14	0.0230	0.080
Locations × varieties............	6	1.98	0.0162	0.068
Locations × seasons × varieties.......	6	2.01	0.0143	0.015
Blocks within locations and seasons..	24	1.21	0.0144	0.097**
Error............................	72	0.99	0.0171	0.046

**Highly significant.

In these studies a question arises concerning the environmental and genetic associations of these properties. This question is answered in part by calculation of the covariances. It may be recalled from information under Experimental Methods that 50 pairs of each combination of these variables at each location are available for the calculations, or 150 pairs for all locations. The correlations are shown in Table 5. In 1941 the correlations of length with fineness between varieties are all significant, but they are not high enough for prediction. In 1942 they are too low to have any significance. The correlations of length with strength, and fineness with strength, between varieties show no significance. All the correlations between locations are high. There are only three locations, however, with but one degree of freedom for testing significance, and these correlations are not statistically significant. The correlations within varieties, or error interaction, are not high. They are both positive and negative for a

given association, so that other factors of environment evidently are operating on the expressions of association between these variables.

TABLE 5.—*Covariance analysis giving simple correlations of length with fineness, length with strength, and fineness with strength of cotton lint between and within varieties and between locations.*

Locations	Between varieties						Within varieties					
	1941			1942			1941			1942		
	L×F*	L×S	F×S	L×F	L×S	F×S	L×F	L×S	F×S	L×F	L×S	F×S
Tiptonville.....	.656	−.189	.187	.273	−.248	.358	−.193	.180	−.062	−.376	.373	−.117
Jackson.......	.679	−.049	.048	.252	−.358	.069	−.358	.209	.134	−.136	.480	−.302
Knoxville......	.674	−.087	.101	.272	−.167	.643	.045	.125	−.404	−.141	.184	−.023
All locations....												
Between varieties.........	.699	−.112	.171	.266	−.354	.338	−.169	.149	−.107	−.187	.053	.088
Between locations........	.989	−.703	−.791	.991	−.902	−.946						

*L = Length; F = Fineness; S = Strength.

Some evidence of the trend of association between the variables is observed in the correlations between varieties. All the correlations of length with fineness and fineness with strength are positive both seasons. All those of length with strength are negative. Some weight may be given to the association of length with fineness by the partial correlations in Table 6. The simple correlation of this association is increased very little in 1941 by either of the partial or multiple correlations.

TABLE 6.—*Covariance analysis giving partial and multiple correlations of length, fineness, and strength of cotton lint between varieties and between locations.*

All locations	1941			1942		
	r12.3*	r23.1	r13.2	r12.3	r23.1	r13.2
Between varieties.....	.734	−.314	.285	.438	−.489	.498
Between locations....	.992	−.942	.918	.984	−.893	.800
	R†	R‡		R†	R‡	
Between varieties....	.743	.366		.534	.567	

*Length = 1; Fineness = 2; Strength = 3.
†Fineness = Dependent variable.
‡Strength = Dependent variable; Length = Independent variable.

PRACTICAL CONSIDERATIONS

Recently, some of the mills have become interested in cotton varieties, and this is very encouraging to the plant breeder. But the mills should not confuse the genetic expression of the varieties with

the environmental influence upon these cotton-lint properties. For example, Stoneville 2B is significantly longer, finer, and weaker at Tiptonville than at Jackson, only 75 miles distant. There is a mass effect of the environment upon these properties in a particular area. Rainfall, temperature, water-holding capacity of the soil, and other factors may contribute to this environment. The response of variety in a given area should be studied from season to season.

The plant breeder will observe that fineness and strength are affected by environment in much the same way as length. It is shown in Table 2 that strength is especially susceptible to small changes in soil fertility. It is suggested that a small remnant of all progenies be grown under the same soil conditions every year.

The correlations in Tables 5 and 6 are somewhat confusing as to whether the association is genetic or environmental. In these correlations length is assumed to be the independent variable when associated with fineness and strength. The cotton fiber begins its growth as a cell. No further division of the nucleus takes place as the cell elongates. Elongation, therefore, is initiated first, followed by the formation of cellulose particles. From present knowledge of these structures there is no justification for assuming fineness as the independent variable in its association with strength, or *vice versa*. All the correlations of this association, however, are low, and these two variables are believed to act independently of each other.

Under these methods of measurement, the three lint properties may be considered as genetically independent, with the exception that in 1941 there is some evidence of association between length and fineness. Their association, however, as the product of environmental conditions is important. In 1941, at Jackson, when the fibers of all the varieties were shorter, they were also coarser and stronger. In 1942, at Knoxville, when the fibers were considerably longer, they were finer and weaker.

The data do not include a large population of varieties, such as are found over the cotton belt. Hence, this small population of varieties, though representative of most varieties in the eastern states, does not give a clear conception of the regression functions. The low correlations of length with fineness in 1942 may be attributed in part to the short range in length of the varieties as compared with the higher correlations and wider range in 1941. Tests for linearity on the association of length with fineness showed no significant departure from linear regression in 1941, but this is not true in 1942. It is recalled (Table 5) that some trends are shown for the correlations between varieties. All the associations of length with fineness and fineness with strength are positive, while all those of length with strength are negative.

SUMMARY

Measurements are given on the properties of length, fineness, and strength of cotton lint. The measurements were made on the fibrograph, arealometer, and Pressley fiber strength tester.

These lint properties are definitely genetic characters of the cotton plant, and varieties show significant differences in their expression.

Environmental conditions of the area where a variety is grown have an important influence upon the expression of the three lint properties.

These lint properties may be considered independent genetically, but, under variable environments, fineness follows length in a positive manner, while strength follows length in a negative manner.

LITERATURE CITED

1. HERTEL, K. L. Application of the seed cotton Fibrograph to lint cotton. Jour. Tenn. Academy Sci., 11:147–152. 1936.
2. ————, and ZERVIGON, M. C. An optical method for the length analysis of cotton fibers. Textile Res., 6:331–339. 1936.
3. ————. A method of fibre-length analysis using the Fibrograph. Textile Res., 10:510–525. 1940.
4. ————. Cotton fiber-length determination using the Fibrograph. Amer. Soc. Testing Mater. Bul., Aug.: 25–27. 1942.
5. PRESSLEY, E. H. Lint strength tests. Ariz. Agr. Exp. Sta. Ann. Rpt., 51:86–87. 1940.
6. ————. A cotton fiber strength tester. Amer. Soc. Testing Mater. Bul., Oct.: 13–17. 1942.
7. SULLIVAN, R. R., and HERTEL, K. L. Surface per gram of cotton fibers as a measure of fiber fineness. Textile Res., 11:30–38. 1940.

FURTHER COMPARISONS OF PLANTS WITH DIFFERENT CHROMOSOME NUMBERS IN RESPECT TO CHEMICAL COMPOSITION[1]

J. T. SULLIVAN[2]

ONE OF the consequences of induced polyploidy may be the increase in size and volume of the plant cell. If this occurs, the chemical composition of the plant may be altered to contain a larger proportion of soluble cell constituents and a smaller proportion of structural constituents. Preliminary investigations in comparing the composition of diploid and tetraploid ryegrass (*Lolium perenne* L.) have been reported (7).[3] Tetraploid ryegrass was found to be higher than diploid in all forms of sugars and in the proportion of dry matter soluble in alcohol. Differences in crude fiber were not significant.

Similar comparisons between plants of different chromosome numbers have been made by Kostoff and Axsamitnaya (3) who found that tetraploid tomatoes contain more water, protein, and soluble carbohydrate and less ash, starch, cellulose, and hemicellulose than the diploids. The same authors found no differences between diploid and tetraploid petunias. Many other reports have appeared concerning the relative amounts of miscellaneous chemical substances in plants of different chromosome numbers. Discussions of these studies may be found in papers by Dermen (2) and O'Mara (5).

The present paper contains the results obtained in a further study of diploid and tetraploid ryegrass and in a comparison of tetraploid and octoploid white clover, *Trifolium repens* L.

COMPARISON OF DIPLOID AND TETRAPLOID RYEGRASS GROWN IN FIELD ROWS

Diploid and tetraploid plants of perennial ryegrass of six clones originating as previously described (4, 7) were set out in the field in June, 1939, in 3-foot rows randomized in triplicate. Four of these clones were among the five previously reported. Samples of the top growth were gathered for chemical analysis from each row June 5 to 8, 1940. All plants were heading at this time but not yet in flower. There was some variation among different clones in maturity as indicated by the flowering date (determined later on undisturbed plants), but there was no difference in this respect between the diploid and tetraploid plants arising from the same original plant. Not all samples were gathered on the same day, but all three replications of the diploid and

[1]Contribution No. 63 of the U. S. Regional Pasture Research Laboratory, Division of Forage Crops and Diseases, Bureau of Plant Industry, Soils, and Agricultural Engineering, Agricultural Research Administration, U. S. Dept. of Agriculture, State College, Pa., in cooperation with the northeastern states. Received for publication January 12, 1944.

[2]Physiologist. Acknowledgments are due to Doctors S. S. Atwood, W. M. Myers, and V. G. Sprague of this Laboratory for furnishing the plant material and also to Doctor Myers for assistance in the statistical analysis.

[3]Figures in parenthesis refer to "Literature Cited", p. 543.

tetraploid plants with a common origin were sampled at one time. Yields were not determined.

The plant material was preserved in boiling alcohol and extracted with 80% alcohol in the usual manner. Analyses were made separately on each replication for the percentage of dry matter, the proportion of dry matter soluble in alcohol, and percentages of soluble and insoluble nitrogen, reducing sugars, sucrose, fructosan, cellulose, and lignin (Table 1). For brevity, the analytical data for the six clones and the three replications have been averaged. In the statistical treatment of the data, the analysis of variance was used.

TABLE 1.—*The average composition of the tops of diploid and tetraploid ryegrass plants grown in field rows.*

Composition	Av. of diploid plants from six clones, three replications, %	Av. of tetraploid plants from six clones, three replications, %	F values for difference between chromosome numbers†	F values for differences between clones‡	F values for interaction between chromosome numbers and clones§
		On Fresh Weight Basis			
Dry matter........	22.96	22.14	8.42**	17.45**	——
		On Dry Weight Basis			
Soluble matter......	29.69	30.60	5.03*	37.03**	——
Soluble N..........	0.35	0.38	3.16	4.76**	——
Insoluble N........	1.89	1.96	1.75	24.69**	1.51
Total N...........	2.24	2.34	2.31	17.70**	1.29
Reducing sugars....	4.87	4.82	——	7.08**	——
Sucrose...........	5.66	6.43	11.43**	20.32**	1.37
Total sugars........	10.53	11.26	11.98**	32.12**	2.65
Fructosan..........	2.40	2.26	——	18.39**	——
Cellulose..........	24.76	24.38	2.98	65.66**	2.78*
Lignin.............	5.40	5.31	——	131.70**	3.56*

†F values for P of 0.05 and P of 0.01 are 4.30 and 7.94, respectively.
‡F value for P of 0.01 is 3.99.
§F value for P of 0.05 is 2.68.
*Exceeds 5% point.
**Exceeds 1% point.

Composition differences between diploid and tetraploid plants were of small magnitude. However, the tetraploids were significantly lower in percentage dry matter, i.e., higher in moisture, and higher in sucrose and total sugars and in the proportion of the dry matter soluble in 80% alcohol. The structural constituents, lignin and cellulose, were lower in the tetraploids but not significantly so. These results agree substantially with those previously reported. Differences between clones were highly significant with respect to every constituent studied. Such differences between clones are not surprising and are often found. In this material a contributing cause to these differences may have been the fact that the clones were not all at the same relative stage of maturity when sampled. Interactions between clones and chromosome numbers were significant for cellulose and lignin and the

F value was almost great enough to show significance for total sugars. There is indicated a differential reaction of different genotypes to chromosome doubling.

COMPARISON OF DIPLOID AND TETRAPLOID RYEGRASS GROWN IN GRAVEL CULTURES

Diploid and tetraploid plants arising from four different clones of perennial ryegrass were grown in the greenhouse in 1-gallon pots filled with coarse gravel and supplied with complete nutrient solution by automatic irrigation. One-half of the pots containing plants of a given chromosome number received a high-nitrate and the other half a low-nitrate nutrient. After the plants had become well established, they were cut to a uniform height of 2 inches on December 8, 1939. Thereafter one-third of each group was clipped to the same level every 2 weeks, another third every 4 weeks, and the remaining third allowed to grow for 12 weeks before being similarly cut. Three successive clippings were made of the plants cut every 2 weeks as well as those cut every 4 weeks, but only one clipping was made for the plants cut after 12 weeks' growth. These clippings were analyzed as before. Each sample taken for analysis represented a composite of the clippings from three replicated pots (each containing six plants), all of the same clone and chromosome number, cut at the same time, and receiving the same nutrient solution and clipping treatment. Analyses were made for percentage dry matter, percentage of the total dry matter soluble in alcohol, and percentages of reducing sugars, sucrose, and fructosan, and soluble and insoluble nitrogen. The weights of the clippings were also determined and they, together with some vegetative and physiological characteristics of the plants, will be described in other papers.

Since a tabulation of the complete data would be lengthy, a partial condensation has been made by combining into averages the data of the various clones and of the several dates (Table 2). An analysis of variance was calculated of the data for the dry matter and the sugar contents for the plants cut every 2 weeks and every 4 weeks, and part of this is presented in Table 3. All the fourth order and the third order interactions not involving both nitrogen and clipping treatments were used as error. The data for the plants cut only at 12 weeks were not included in the statistical analysis as only one date was available instead of the three dates of the other two clipping treatments. Statistical analysis was not made for fructosan as it was absent in many samples. Neither was statistical analysis made of the nitrogen contents as by inspection it was apparent that this constituent did not vary significantly according to chromosomal differences.

The results indicate that the percentage of dry matter is lowered by increase in chromosome number. It is also significantly affected by the nitrogen level, frequency of clipping, date of clipping, and clone. Interactions of chromosome numbers with nitrogen supply and with frequency of clipping are significant. Inspection indicates that the percentage of dry matter is not affected by the chromosome number in the material allowed to grow for 12 weeks.

TABLE 2.—*The average composition of the tops of four clones of diploid and tetraploid ryegrass plants grown in the greenhouse in gravel culture.*

	High-N nutrient						Low-N nutrient					
Age of leaf material, weeks	2		4		12		2		4		12	
No. of successive cuttings analyzed separately but averaged in this table	3		3		1		3		3		1	
Chromosome numbers	2n	4n	2n	4n	2n	4n	2n	4n	2n	4n	2n	4n
On fresh weight basis:												
Dry matter	13.77	13.28	13.00	13.73	19.05	19.05	17.37	16.58	19.32	18.74	27.71	28.30
On dry weight basis:												
Soluble matter	35.78	37.03	31.08	32.28	29.20	30.30	32.28	32.45	29.48	30.21	25.62	25.92
Reducing sugars	0.33	0.35	0.65	0.77	1.81	2.23	0.37	0.37	0.69	0.72	1.28	1.34
Sucrose	7.55	8.09	5.24	5.42	5.15	5.26	9.35	9.31	7.94	8.17	4.99	5.18
Total sugars	7.90	8.45	5.89	6.19	6.96	7.50	9.72	9.68	8.63	8.89	6.26	6.51
Fructosan	0	0	0	0	0.55*	0.54*	0	0	2.03†	1.67†	8.77	8.18
Soluble N	1.57	1.57	1.07	1.11	0.50	0.43	0.38	0.36	0.30	0.30	0.29	0.32
Insoluble N	3.58	3.55	3.42	3.40	2.22	2.12	2.93	3.04	2.06	2.05	1.14	1.20
Total N	5.15	5.12	4.49	4.51	2.71	2.55	3.31	3.37	2.37	2.36	1.43	1.52

*Av. of four samples but only two contained measurable amounts.
†Av. of 12 samples but only 7 contained measurable amounts.

TABLE 3.—*Analysis of variance of part of data for the composition of ryegrass plants sampled every 2 weeks and 4 weeks and summarized in Table 2.*

	F values for variation due to differences in					Interactions of			
	Chromosome numbers (Chr)	Nitrogen level (N)	Frequency of clipping (F)	Date of clipping (D)	Clone (Cl)	Chr×N	Chr×F	Chr×D	Chr×Cl
Value necessary for significance for P of .05	4.02	4.02	4.02	3.17	2.78	4.02	2.78	3.17	2.78
Value necessary for significance for P of .01	7.12	7.12	7.12	5.01	4.16	7.12	4.16	5.01	4.16
Dry matter	4.91*	1268.50**	54.87**	14.47**	98.44**	9.86**	7.88**	2.40	1.65
Soluble matter	13.11**	159.67**	243.16**	16.93**	17.60**	2.84	—	3.15	—
Reducing sugars	1.48	—	120.13**	4.07*	2.01	—	1.13	—	—
Sucrose	2.28	193.98**	153.50**	118.94**	7.72**	—	—	—	3.88*
Total sugars	3.17	199.80**	104.48**	119.49**	7.47**	1.15	—	—	4.55**

*Exceeds 5% point.
**Exceeds 1% point.

The proportion of dry matter soluble in alcohol is increased by chromosome doubling. It is also affected by all the other experimental variables. Inspection indicates that the percentage of the dry matter soluble in alcohol is also higher in the tetraploids in six out of eight pairs of samples of the 12 weeks' growth.

When all clones are averaged, sugars were not found to be significantly affected by chromosome doubling in the 2- and 4-week-old clippings, but the significance of the interactions between chromosome number and clone indicates that clones behave differently. In the eight pairs of samples of the 12 weeks' growth the tetraploids are higher in seven pairs for reducing sugars and sucrose and in all eight pairs for total sugars.

Fructosan was not present in the more frequently cut plants. The number of plants containing fructosan increased as the frequency of cutting and the nitrogen supply decreased. Chromosome number appeared to have no effect on fructosan content. Nitrogen content also was apparently not affected by chromosome number.

COMPARISON OF TETRAPOID AND OCTOPLOID *TRIFOLIUM REPENS* IN THE FIELD

The materials used for comparison were individually spaced white clover plants derived by clonal increase from tetraploid and octoploid sectors of 10 original seedlings (1). Of the 10 clones, 7 were represented by tetraploid and octoploid plants in triplicate, and the remaining 3 in duplicate. Samples of entire leaves, one sample from each plant, were gathered July 22 and 23, 1940. Replications and plants of different chromosome numbers of the same clone were sampled at the same time. The plant material was dried in a warm room and ground in a mill. Analyses were made according to the official methods for feedingstuffs. Additional samples were gathered for crude carotene determination on July 25 to 29, 1940. In cases where plants had been heavily defoliated by the earlier sampling, the sampling for carotene was omitted. Therefore, two clones were represented only by one pair each and one clone by two pairs. An additional harvest for carotene determinations from 30 pairs of plants was made on September 16 to 18 after the plants had recovered from the previous cutting. No attempt was made to measure the yields obtainable during the several cuttings. The procedure for making the carotene analyses was similar to that previously described (6).

The chemical analyses of the clover leaves were made separately on each replication and the data are summarized briefly in Table 4. The octoploid plants were found to be significantly lower in crude fiber and also lower in carotene in September but not in July.

SUMMARY

Comparative chemical analyses were made of diploid and tetraploid perennial ryegrass. In field rows, tetraploid plants were lower in percentage dry matter and higher in sucrose and total sugars and in the proportion of dry matter soluble in alcohol. In similar plants grown in culture solutions in the greenhouse similar results were ob-

TABLE 4.—*The average composition of white clover leaves from 10 clones of tetraploid and octoploid plants.*

	No. of pairs	Tetra-ploid, %	Octo-ploid, %	F values for differences between chromosome numbers
Samples of July 1940				
On fresh weight basis:				
Dry matter	27	24.27	23.61	2.77
On dry weight basis:				
Total N	27	3.73	3.78	1.49
Ash	27	13.85	14.07	—
Fat	27	2.04	2.11	—
Fiber	27	13.58	12.97	29.05**
N-free extract	27	47.17	47.30	—
Carotene, p.p.m. dry weight	25	416	409	—
Samples of Sept. 1940				
Carotene, p.p.m. dry weight	30	403	371	4.91*

*Exceeds 5% point (F value for P of .05 is 4.10).
**Exceeds 1% point (F value for P of .01 is 7.44).

tained, except that tetraploid plants were lower in percentage dry matter only in respect to younger clippings and were higher in sugars only in more mature clippings.

In white clover, octoploid plants were lower in fiber and in carotene than tetraploid plants.

Differences in chemical composition which were found associated with an increase in chromosome number, while of statistical significance in those cases stated, were not however of great magnitude. In general, it may be stated that an increase in chromosome number was frequently associated with an increase in moisture and in the soluble constituents and with a decrease in the structural constituents. The reverse association was not found in any case.

LITERATURE CITED

1. ATWOOD, S. S. Colchicine induced polyploids in white clover. Jour. Amer. Soc. Agron., 36:173–174. 1944.
2. DERMEN, H. Colchicine polyploidy and technique. Botan. Rev., 6:599–635. 1940.
3. KOSTOFF, D., and AXSAMITNAYA, I. A. Studies on polyploid plants. IX. Chemical analyses of diploid and their autotetraploid plants. Compt. Rend. Acad. Sci., U.R.S.S., 2:295–297. 1935.
4. MYERS, W. M. Colchicine induced tetraploidy in perennial ryegrass, *Lolium perenne* L. Jour. Heredity, 30:499–504. 1939.
5. O'MARA, J. G. A photoperiodism accompanying autotetraploidy. Amer. Naturalist, 76:386–393. 1942.
6. SULLIVAN, J. T., and CHILTON, S. J. P. The effect of leaf rust on the carotene content of white clover. Phytopathology, 31:554–557. 1941.
7. ————, and MYERS, W. M. Chemical composition of diploid and tetraploid *Lolium perenne* L. Jour. Amer. Soc. Agron., 31:869–871. 1939.

EFFECT OF PICRIC ACID IN SUPERPHOSPHATE ON TOMATOES AND BEANS AS INDICATED BY GREENHOUSE EXPERIMENTS[1]

L. F. RADER, JR., D. S. REYNOLDS, AND K. D. JACOB[2]

THE attainment of the 1944 food-production goals will require the use of an unprecedented quantity of superphosphate, the manufacture of which will necessitate the utilization of every possible source of sulfuric acid, including spent and waste acids, to the extent that this can be done without the introduction of impurities that are harmful to plants. As a part of an investigation of spent and waste acids from various sources, it has been shown that superphosphates made, respectively, with spent acids from the refining of petroleum products and from the manufacture of high-octane gasoline by the alkylation process are entirely suitable for use as fertilizer (1, 2, 4, 7).[3] In continuation of the investigation, a greenhouse study was made of the agronomic value of superphosphate made with spent sulfuric acid from the manufacture of picric acid (2,4,6-trinitrophenol). The results are given herein.

In World War I picric acid was made mostly, if not entirely, by the nitration of phenol sulfonic acid. At present, however, the preferred method is the so-called dinitrochlorobenzene process which comprises the conversion of dinitrochlorobenzene into dinitrophenol and the nitration of the latter to picric acid by means of a mixture of nitric and sulfuric acids. The picric superphosphate used in the present study was made with spent sulfuric acid from the latter process.

Spent acid from the dinitrochlorobenzene process, as operated by one company, is said to have an average acidity value of 72.2% H_2SO_4 with a range of 72.0 to 72.4%, while the picric acid content ranges from about 1.0 to 1.5% and averages about 1.2%. As reported to the writers, one sample of denitrated spent acid from this process contained 74.12% H_2SO_4 and 1.53% picric acid. Water solutions of superphosphates that contain picric acid have a pronounced yellow color.

REVIEW OF LITERATURE

Although a search of the literature revealed no information relating to the effects of picric acid on the growth of the higher forms of plant life, it is of interest to note the results obtained by several workers in studies of the effects of the compound on the lower forms of plants (fungi and yeasts) and on bacteria. Thus, Martin and Salmon (5) reported that picric acid is more toxic than phenol to the conidial stage of the hop powdery mildew, *Sphaerotheca humuli* (D.C.) Burr., growing on the young leaves of hop plants.

According to Plantefol (9, 10), the nitrophenols are more toxic than phenol to spores of the mold *Sterigmatocystis nigra* in the order of decreasing toxicity:

---

[1]Contribution from Division of Soil and Fertilizer Investigations, Bureau of Plant Industry, Soils, and Agricultural Engineering, Agricultural Research Administration, U. S. Dept. of Agriculture, Beltsville, Md. Received for publication January 28, 1944.

[2]Assistant Chemists and Senior Chemist, respectively. The tomato plants used in this investigation were kindly supplied by F. S. Beecher, Assistant Pathologist, Division of Fruit and Vegetable Crops and Diseases.

[3]Numbers in parenthesis refer to "Literature Cited", p. 550.

2,4-dinitrophenol; *p*-nitrophenol; *m*-nitrophenol and picric acid; *o*-nitrophenol; phenol. For a yeast species designated as No. 121, Newton and Edwards (8) found that the lethal concentrations of picric acid and phenol were 1:250 and 1:110, respectively.

As reported by Tidy (17), the bactericidal power of a 0.165% solution of picric acid toward 24-hour broth cultures of typhoid bacteria was the same as that of a 1.0% solution of phenol. In a study of the sterilizing action of phenols for *Staphylococcus pyogenes aureus*, *Proteus vulgaris* Hauser, *Bacillus typhosus*, and *Vibrio cholerae*, Tetsumoto (16) found the bactericidal effect of picric acid to be higher than that of thymol and phenol. The salts of hydroquinone and thymol had a sterilizing action, while those of the other phenols rather accelerated the growth of the bacteria.

Studies of the effects of phenol on plants have been reported by several workers. True and Hunkel (18) found that the compound at a concentration of 0.0025 *M* (about 235 p.p.m.) prevented the growth of lupine roots. This concentration is very close to that (250 p.p.m.) reported by Schreiner and Reed (14) to have caused the death of wheat seedlings in 8 days in water cultures. In solutions containing 50 and 100 p.p.m. of phenol the tops of the seedlings were alive at the end of 8 days but the roots were dead. The plants in solutions of 5 p.p.m. were slightly poorer than the control plants, but those in 1 p.p.m. were fully as good as the controls.

As indicated by the root growth of soybean seedlings in solution cultures, Eisenmenger (3) found that the toxicity of phenol increased with its concentration in the culture. Within certain limits, the toxicity was decreased by the presence of silica gel or calcium nitrate. As picric acid is more toxic than phenol to fungi and yeasts, it is reasonable to expect that it would also be more toxic to the higher forms of plant life.

MATERIALS AND METHODS

The superphosphates used in this study were made from Florida pebble phosphate rock by a fertilizer manufacturer. The material designated as commercial superphosphate was manufactured in the usual manner with sulfuric acid from the company's customary source of supply. The material designated as picric superphosphate was made experimentally with spent sulfuric acid from the manufacture of picric acid. Analyses of the materials showed total P_2O_5 20.82%, 19.72%; available P_2O_5 18.92%, 18.02%; moisture 6.80%, 10.10%, in the commercial and the picric superphosphates, respectively. The picric superphosphate contained 0.85% picric acid.

The experiments were made in 8-inch, bottom-pierced, clay pots with tomatoes (Pan-America) and snap beans (Bountiful) on Sassafras sandy loam (12 pounds per pot) from the Beltsville Research Center, Beltsville, Md. The soil had a moisture-equivalent value of about 15%. It was passed through an 8-mesh screen and the pH value was adjusted to 6.2 by an addition of calcium carbonate. The pots and their supporting saucers were coated with water-proof varnish.

The pots received a basal treatment of 6-0-10 fertilizer at the rate of 2,000 pounds per acre, in which the nitrogen was derived equally from sodium nitrate and ammonium sulfate and the potash from potassium chloride. As the purpose of the experiments was to determine whether the picric superphosphate is harmful to plants, the rate of application of the superphosphate was varied from 250 to 2,000 pounds of total P_2O_5 per acre (2,000,000 pounds of soil), corresponding to 1,201 to 9,608 pounds of the commercial superphosphate and 1,268 to 10,144 pounds of the picric superphosphate per acre, in order to stimulate the concentrations that may prevail in the root zone under field conditions. At these rates the quantities of picric acid supplied by the picric superphosphate ranged from 10.8 to 86.4 pounds per acre, or 5.4 to 43.2 p.p.m. of soil. In another series of experiments, applications of the commercial superphosphate were made at a uniform rate of 500 pounds of total P_2O_5 per acre, and recrystallized picric acid was applied at rates ranging from 6 to 480 pounds per acre (3 to 240 p.p.m.), corresponding to 0.25 to 20% of the weight of the superphosphate. The basal fertilizer, the superphosphates, and the picric acid (where this material was added separately to the soil) were thoroughly mixed with the upper 6 pounds of dry soil in each pot, but the rates of application were based on the total weight of soil in the pot.

A single tomato plant, from the roots of which the soil had been removed by gentle washing, was transplanted to each of the pots on May 1, 1943. At the time of transplanting, the plants were about 5 inches tall and were exhibiting signs of nitrogen deficiency. The moisture content of the soil was maintained at about 75% of the moisture equivalent. The aerial portions of the plants were harvested on May 27, at which time nearly all the normal plants were in blossom, and were dried in a forced-draft oven at 82°C.

After the tomato plants were removed, certain of the pots of soil were allowed to remain undisturbed in the moist condition for 7 days. The soil was then loosened to a depth of 4 inches and, without further addition of fertilizer, 10 bean seeds were planted at a depth of 2 inches in each pot. The emergence and growth of the beans were observed over a period of 12 days to determine the residual effect of the picric acid originally applied to the tomatoes 33 days previously. The effects on the growing plants of freshly applied picric acid were then determined by adding different quantities of the compound to certain cultures that previously had received no picric acid.

RESULTS

As shown in Table 1, the picric superphosphate used at rates to supply 250 and 500 pounds of total P_2O_5 per acre, corresponding to respective applications of 10.8 and 21.6 pounds of picric acid, had no adverse effect on the dry-matter yields of tomato plants at the end of 26 days. Also, the blossoming of the plants was not retarded. At the rate of 250 pounds of P_2O_5 per acre, the picirc superphosphate produced plants which yielded 12.5% more dry matter than those receiving the corresponding quantity of commercial superphosphate and which were identical with the latter in other respects. With 500 pounds of P_2O_5, the commercial and the picric superphosphate produced practically the same yields of dry matter, despite the fact that plants which received the picric superphosphate showed some marginal "firing", first, of all the leaves, and later of the bottom leaves only. At a level of 1,000 pounds of P_2O_5 per acre, the yield of dry matter with the picric superphosphate (supplying 43.2 pounds of picric acid per acre) was 79.2% of that with the commercial superphosphate. At the 2,000-pound level the effect of the picric acid (86.4 pounds per acre) was to suppress completely the growth of the plants.

As with the smallest application of picric superphosphtae (10.8 pounds of picric acid per acre), the growth of tomatoes seemed to be stimulated by the application of a small quantity of recrystallized picric acid (6 pounds per acre) in combination with the commercial superphosphate (Table 1). With larger quantities of picric acid, however, the toxic action of the recrystallized compound seemed to be greater than that of similar amounts of picric superphosphate. For example, 30 pounds of recrystallized picric acid had a somewhat greater effect in retarding plant growth and increasing leaf "firing" and "mottling" (occurence of yellowish spots or areas between the leaf veins) than did 43.2 pounds of the compound in the form of picric superphosphate.

The apparent beneficial action of the small applications of picric acid on plant growth may have been due wholly or in part to a direct stimulative effect of the compound or, indirectly, to its action in alternating the soil microflora. It is well known that partial sterilization of the soil, with phenol, for example, is often markedly beneficial to plants subsequently grown therein (6, 12, 13).

TABLE 1.—*Effect of picric acid on growth of tomatoes.*

Treatment	Rate of application per acre		Dry weight per plant, grams*	Condition of plants at	
	Total P_2O_5, pounds	Picric acid, pounds		1 week	2 weeks
No fertilizer	None	None	1.85	Yellowish green	Green, stunted
N, K	None	None	2.09	Green, vigorous	Green, slightly stunted
N, K, commercial superphosphate	250	None	7.75	Green, vigorous	Green, vigorous
N, K, commercial superphosphate	500	None	9.58	Green, vigorous	Green, vigorous
N, K, commercial superphosphate	1,000	None	10.38	Green, vigorous	Green, vigorous
N, K, commercial superphosphate	2,000	None	9.59	Slightly stunted	Green, vigorous
N, K, picric superphosphate	250	10.8	8.72	Green, vigorous	Green, vigorous
N, K, picric superphosphate	500	21.6	9.44	Normal growth, edges of all leaves "fired"	Normal growth, edges of bottom leaves "fired"
N, K, picric superphosphate	1,000	43.2	8.22	Slightly stunted, lower leaves dead	Slightly stunted
N, K, picric superphosphate	2,000	86.4	1.75	Greatly stunted, lower leaves dead	Greatly stunted, all leaves "fired" and "mottled"
N, K, commercial superphosphate, picric acid	500	6.0	11.25	Green, vigorous	Green, vigorous
N, K, commercial superphosphate, picric acid	500	18.0	7.98	Leaves slightly "fired" and "mottled"	Only bottom leaves "fired" and "mottled"
N, K, commercial superphosphate, picric acid	500	30.0	6.30	Leaves "fired" and "mottled"	Stunted, all but terminal leaves "fired"
N, K, commercial superphosphate, picric acid	500	60.0	0.48	Leaves "fired" and "mottled"	Greatly stunted, all leaves "fired" and "mottled"
N, K, commercial superphosphate, picric acid	500	120.0	0.80	All but terminal leaves dead	All but terminal leaves dead
N, K, commercial superphosphate, picric acid	500	240.0	—	Plants killed	—
N, K, commercial superphosphate, picric acid	500	480.0	—	Plants killed	—

*Average of two replications with the unfertilized pots and those receiving commercial superphosphate plus picric acid and of four replications with the other treatments.

Although there are inconsistencies in the results (Table 2), contact of picric acid with moist soil for 33 days rendered the compound innocuous to the subsequent emergence and growth of beans, except at very high rates of application. Even with 240 pounds of picric acid per acre, the effect was to delay emergence only slightly. With 480 pounds of picric acid, emergence of the sprouts was entirely prevented for 8 days, but at the end of 12 days the percentage emergence was higher than in some cultures that received much smaller quantities of picric acid. The slow emergence of the sprouts was reflected in the much shorter height of the plants at 12 days, though the leaves were normal in color and size. The stems and cotyledons of the plants in cultures that received 120 pounds or more of picric acid per acre were colored a distinct yellow for several days after the emergence of the sprouts, and the development of the root systems was considerably retarded. These effects and the yellow color of the surface soil were progressively less noticeable with decrease in the quantity of picric acid applied.

TABLE 2.—*Effect of residual picric acid on emergence and growth of beans.*

Treatment	Rate of application per acre		Percentage emergence of beans in					Average height of plants at 12 days, cm
	Total P_2O_5, pounds	Picric acid, pounds	5 days	6 days	8 days	10 days	12 days	
No fertilizer	None	None	45.0	85.0	85.0	85.0	85.0	19.5
N, K	None	None	57.5	97.5	97.5	97.5	97.5	22.0
N, K, commercial superphosphate	250	None	5.0	75.0	92.5	95.0	95.0	21.0
N, K, commercial superphosphate	500	None	0.0	45.0	85.0	87.5	87.5	21.0
N, K, picric superphosphate	250	10.8	0.0	42.5	85.0	87.5	87.5	21.5
N, K, picric superphosphate	500	21.6	0.0	55.0	92.5	92.5	92.5	22.0
N, K, picric superphosphate	1,000	43.2	0.0	22.5	85.0	90.0	95.0	19.0
N, K, picric superphosphate	2,000	86.4	2.5	45.0	92.5	100.0	100.0	21.0
N, K, commercial superphosphate, picric acid	500	6.0	0.0	75.0	95.0	100.0	100.0	21.5
N, K, commercial superphosphate, picric acid	500	18.0	0.0	55.0	65.0	65.0	65.0	20.0
N, K, commercial superphosphate, picric acid	500	30.0	0.0	30.0	65.0	75.0	75.0	19.0
N, K, commercial superphosphate, picric acid	500	60.0	5.0	60.0	85.0	85.0	85.0	21.0
N, K, commercial superphosphate, picric acid	500	120.0	0.0	35.0	60.0	95.0	100.0	20.0
N, K, commercial superphosphate, picric acid	500	240.0	0.0	10.0	70.0	80.0	85.0	20.0
N, K, commercial superphosphate, picric acid	500	480.0	0.0	0.0	0.0	40.0	80.0	10.0

As with phenol and the wide variety of other organic compounds studied by Matthews (6), Robbins (11), and Sen-Gupta (15), the detoxification of picric acid in soil is probably brought about by a combination of chemical, physical, and biological processes, particularly those involving the soil microflora.

In order to obtain further information concerning the effect of picric acid on beans, the picrate-free bean cultures that had received nitrogen and potassium with and without commercial superphosphate (250 and 500 pounds of P_2O_5 per acre) were thinned to five evenly spaced plants (average height about 20 cm) per pot, and duplicate pots were treated with recrystallized picric acid at the respective rates of 9, 18, 24, 30, and 60 pounds per acre. The solid picric acid was placed in circular depressions about 2 inches deep and 2 inches in diameter in the surface soil at the centers of the pots. The moisture content of the soil was maintained at about 75% of the moisture equivalent, and the reactions of the plants were observed over a period of 14 days.

After 5 days, 4 of the 10 plants in the cultures with 60 pounds of picric acid rapidly developed "mottled" leaf, lost the bottom larger leaves within 48 hours, and continued to be adversely affected for the duration of the test. With the 30-pound application of picric acid, only two plants (one in each pot) developed "mottled" leaf and then only to a relatively small degree. The smaller applications of picric acid showed no toxic effects. Inasmuch as the tomato plants showed definite signs of injury from fresh applications of pure picric acid at the rate of 18 pounds per acre, while the bean plants were unaffected by similarly made applications of 24 pounds and were only slightly injured at the 30-pound rate, it appears that beans are more resistant than tomatoes to injury by the compound.

Although the data indicate that superphosphate containing 0.85% picric acid can be used safely, at least on tomatoes and beans, at the rate of 500 pounds of total P_2O_5 (about 2,500 pounds of superphosphate) per acre, corresponding to an application of approximately 21 pounds of picric acid, it would be preferable to reduce the concentration of the picric acid in the superphosphate to 0.25% or less, in order to provide a wider margin of safety. This can be done easily by adjusting the proportions of spent acid and picrate-free acid used in the manufacture of the superphosphate.

As a result of this investigation, a considerable quantity of spent sulfuric acid from the manufacture of picric acid has been used in the production of superphosphate. Analyses of several samples taken from different shipments of the superphosphate showed the presence of 0.11% or less of picric acid.

SUMMARY

Greenhouse pot experiments with tomatoes and snap beans were carried out on a Sassafras sandy loam soil to obtain information on the plant growth effects of superphosphate produced with spent sulfuric acid from the manufacture of picric acid. The superphosphate contained 0.85% picric acid.

The superphosphate used at rates to supply 250 and 500 pounds of total P_2O_5 per acre, corresponding to respective applications of 10.8

and 21.6 pounds of picric acid per acre, had no adverse effect on the dry weight yields of tomato plants at the end of 26 days. With higher rates of application the injurious effects of the picric acid, which were characterized by "mottling" and "firing" of the leaves and by stunted growth, were increasingly apparent. Although the plants were not completely killed, no growth was made when the picric superphosphate was applied at a rate to supply 2,000 pounds of total P_2O_5 and 86.4 pounds of picric acid per acre.

Picric acid in the form of picric superphosphate appeared to be somewhat less toxic than the recrystallized pure compound.

There was evidence that the toxic level of picric acid for tomatoes may be lower than that for snap beans.

Contact of picric acid with moist soil for 33 days rendered the compound innocuous to the subsequent emergence and growth of snap beans, except at very high rates of application. Even with 240 pounds of picric acid per acre, the effect was to delay emergence only slightly.

Because of the limited scope of this investigation and in order to provide a wide margin of safety, it is recommended that the proportions of spent acid and picrate-free acid used in making superphosphate be adjusted so that the product will contain not more than 0.25% picric acid.

LITERATURE CITED

1. Brown, B. E., Campbell, J. C., Hawkins, Arthur, Houghland, G. V. A., and Jacob, K. D. An evaluation of sludge-acid and alkylation-acid superphosphates as sources of phosphorus in potato fertilizers: Field studies in Maine, New Jersey, Pennsylvania, and Virginia. Amer. Potato Jour., 20:89–95. 1943.
2. ———, Jacob, K. D., and Reid, F. R. Plant culture and nitrification studies with sludge-acid superphosphate. Amer. Fert., 96(7):5–6, 24, 26. 1942.
3. Eisenmenger, Walter S. Factors modifying the toxicity of phenol. Plant Physiol., 6:325–331. 1931.
4. Jacob, K. D., and Armiger, W. H. Field experiments with alkylation-acid superphosphate. Jour. Amer. Soc. Agron., 36:281–286. 1944.
5. Martin, H., and Salmon, E. S. The fungicidal properties of certain spray-fluids, XI. Synthetic solvents. Jour. Agr. Sci., 24:469–490. 1934.
6. Matthews, Annie. Partial sterilization of soil by antiseptics. Jour. Agr. Sci., 14:1–57. 1924.
7. Miller, Eilif V., and Jacob, K. D. Agronomic value of alkylation-acid superphosphate as indicated by greenhouse and laboratory experiments. Jour. Amer. Soc. Agron., 36:274–280. 1944.
8. Newton, William, and Edwards, Howard I. Chemical compounds lethal to yeasts and bacteria. Sci. Agr., 12:564–567. 1932.
9. Plantefol, L. Sur la toxicité de divers phénols nitrés pour le Sterigmatocystis nigra Acad. des Sci. Compt. Rend., 174:123–126. 1922.
10. ———. Études sur l'action du dinitrophénol 1–2–4 (Thermol). VII. Action du dinitrophénol 1-2-4 sur la respiration de cellules et tissus végétaux. Ann. de Physiol. et Physiochem. Biol., 8:127–156. 1932.
11. Robbins, William J. The cause of the disappearance of cumarin, vanillin, pyridine and quinoline in the soil. Ala. Agr. Exp. Sta. Bul. 195. 1917.
12. Russell, Edward John, and Hutchinson, Henry Brougham. The effect of partial sterilization of soil on the production of plant food. Jour. Agr. Sci., 3:111–144. 1909.
13. ———, ———. The effect of partial sterilization of soil on the production of plant food. II. The limitation of the bacterial numbers in normal soils and its consequences. Jour. Agr. Sci., 5:152–221. 1913.

14. SCHREINER, OSWALD, and REED, HOWARD S. The toxic action of certain organic plant constituents. Bot. Gaz., 45:73–102. 1908.
15. SEN-GUPTA. NAGENDRA NATH. Dephenolisation in soil. Jour. Agr. Sci., 11:136–158. 1921.
16. TETSUMOTO, SOGO. Sterilizing action of phenols. Jour. Agr. Chem. Soc. Japan, 16:299–305. 1940.
17. TIDY, H. L. The strength of picric acid as an antiseptic. Lancet, 189:604–605. 1915.
18. TRUE, RODNEY H., and HUNKEL, CARL G. The poisonous effect exerted on living plants by phenols. Bot. Centbl., 76:289–295. 1898.

AGRONOMIC AFFAIRS

ÉMILE DEMOUSSY (1866–1942)

THE death has just been announced of Doctor Émile Demoussy, formerly Professor of Plant Physiology of the Institut Agronomiques, Paris (Bul. Soc. Chim. Biol., 25:236–237, 1943). Doctor Demoussy is to be remembered as a close collaborator of the brilliant French agronomist P.-P. Deherain, and as a member of that famous group of agronomists and soil chemists that have contributed their share towards making this group of French scientific workers, beginning with the epoch-making discoveries of Boussingault, pioneers in this field.

Doctor Demoussy was connected with the French Institute of Agronomy for a great many years, having been appointed there as instructor in Agricultural Chemistry, in 1898, and made full Professor in 1921. He was retired from active duty in 1933. He was one of the founders and a former President of the French Society of Biological Chemists. He will best be remembered for his work with Deherain on the decomposition of organic matter in the soil, on the production of CO_2, later to be followed by various studies on the nutrition of plants, germination of seeds, gaseous exchange between plants with the atmosphere, the phenomena of toxicity, and a number of investigations on soil transformations.

Doctor Demoussy was a quiet, unassuming, highly humane person; he was known very little outside of a close circle of friends and colleagues. It was indeed a great privilege to have had an opportunity to meet this great agricultural scientist and to become inspired by his ideas and profound understanding of the principles of soil fertility and plant growth.—SELMAN A. WAKSMAN.

THE PROCEEDINGS OF THE SOIL SCIENCE SOCIETY

PROGRESS in the publication of the 1943 PROCEEDINGS of the Soil Science Society is distressingly slow. It is now apparent that the volume will be much delayed beyond June 15th, the date first set for its appearance. The copy has been in type for sometime, but labor shortages and other difficulties have interferred seriously with assembling and make-up of the pages. Fortunately, paper stocks are on hand ready to complete the job once the make-up has been finished and the proofs submitted to and returned by the authors.

THE 1944 MEETINGS

THE annual meetings of the American Society of Agronomy and the Soil Science Society of America will be held at the Netherland-Plaza Hotel in Cincinnati, Ohio, November 15 to 17, inclusive.

Professor I. J. Johnson of Iowa State College, Ames, Iowa, Chairman of the Crops Section, has issued a call on behalf of the Program Committee for volunteer papers to be presented before the Crops Section in November. Papers should be 10 to 15 minutes in length. The title and a brief abstract should be sent to Professor Johnson not later than September 1st to permit classification and assignment to the proper subsection of the program.

NATIONAL ROSTER OF SCIENTIFIC AND SPECIALIZED PERSONNEL

THE National Roster of Scientific and Specialized Personnel in the War Manpower Commission is the agency of the Federal Government which, since 1940, has served as a central registry for persons possessing professional or scientific qualifications. All professionally qualified young engineers, chemists, physicists, geologists, mathematicians, etc., should be registered with the National Roster.

The Roster has been assigned the responsibility of obtaining the best utilization of professional and scientific personnel. In the light of recent Selective Service directives which will result in the induction of many thousands of professionally and scientifically qualified men under the age of 26, it is important that these particular individuals who will enter the armed forces immediately notify the Roster of the branch of the armed forces they are entering, the date and place of their induction and, after induction, their serial number. Obviously the Roster, as a civilian agency of the Government, has no responsibility in the assignment of its registrants within the armed forces. At the request of the War and Navy Departments, however, the Roster does furnish advice to the Office of the Adjutant General, War Department, and the Bureau of Naval Personnel, Navy Department, concerning the specialized training and qualifications of those of its registrants who are inducted into the Army or Navy.

It is conceivable that it may become imperative in the future to withdraw a number of professionally and scientifically qualified men from the armed forces in order to assign them to important research or production work in civilian war industry. The Roster's records are sufficiently detailed to permit intelligent selection of persons possessing professional qualifications in practically every kind of specialized field and it would probably be called upon to assist in any such assignment. It is important, therefore, that persons possessing professional or scientific qualifications register with the Roster and advise it immediately concerning any change in their status. Communications should be addressed to the National Roster of Scientific and Specialized Personnel, 1006 U Street, N. W., Washington 25, D. C.

JOURNAL

OF THE

American Society of Agronomy

VOL. 36 JULY, 1944 NO. 7

THE SUGAR BEET IN THE WAR AND POST-WAR PERIOD FROM THE STANDPOINT OF THE AGRICULTURAL ENGINEER[1]

E. M. MERVINE[2]

THE thinning and harvesting labor requirements of present hand methods in growing sugar beets are excessive, requiring utilization of transient labor in both spring and fall. From the agricultural engineering point of view these peak labor demands need to be leveled to the extent that with proper farm management of other crops, a smaller labor crew may be maintained throughout the year to handle all of the farm work in a balanced program. Usually, the labor requirements for sugar beet production have stood out in the grower's mind to the exclusion of some of the other factors, but now that there is promise that the labor curve can be very definitely smoothed out, the study of some of the other factors is appropriate.

The cost of machinery must, quite properly, be charged against these new highly mechanized operations in sugar beet growing. With the purchase of new and specialized equipment, the machinery cost per acre or per ton of product may be somewhat higher than it was when more of the operations were performed by hand or when smaller units were used. It is possible, however, that with a more mechanized system larger acreages will be in order, with the consequent lowering of unit acre costs. There have been several accepted schemes of evaluating these costs, systems of figuring based on the probable life of the equipment, and an expected cost of repairs and interest as well as operating costs incident to the use of power. In this study, these systems of computations were used and were found to differ very little.

Too frequently plans have been evolved for growing sugar beets with the entire thought centered on this one crop to the exclusion of other crops of the grower. If a proposed system calls for two tractors and the remaining crops have no need for the second tractor, then the system is illogical. Hence it is necessary to consider the farm

[1]Contribution to the symposium on "Sugar Beets in the War and Post-War Periods" held at the annual meeting of the Society in Cincinnati, Ohio, November 10, 1943. Received for publication February 28, 1944.

[2]Agricultural Engineer, Bureau of Plant Industry, Soils, and Agricultural Engineering, U. S. Dept. of Agriculture, cooperating with Colorado Agricultural Experiment Station, Fort Collins, Colo.

TABLE 1.—*Comparison of man-hours per acre and machine power costs per acre in growing sugar beets under present and under mechanized practice.**

Operation	Man-hours per acre				Machine-power cost per acre			
	Present practice		Mechanized practice		Present practice		Mechanized practice	
	Itemization	Man-hours	Itemization	Man-hours	Itemization	Cost	Itemization	Cost
Manuring	1 man, 2 horses 1½-ton spreader	7.7	2 men, 2 tractors, 2 spreaders, 1 loader	3.0	2 horses Spreader	$ 1.92 0.85	2 tractors 2 spreaders 1 loader	$ 4.50 0.96 0.19
Plowing	1 man, 3 horses 16-inch plow	4.0	1 man, 1 tractor, 1 two-bottom plow	1.3	3 horses Plow	1.50 0.47	1 tractor 1 plow	.96 0.51
Harrowing	1 man, 4 horses 1 single-disk harrow 1 drag harrow	3.47	1 man, 1 tractor double disk, drag harrow	1.0	4 horses Disk Drag harrow	1.73 0.35 0.22	1 tractor Disk and drag	0.75 0.20
Planting	1 man, 2 horses 1 planter	1.0	2 men, 1 tractor, 1 planter	1.0	2 horses Planter	0.25 0.43	1 tractor Planter	0.75 0.43
Crust breaking	1 man, 2 horses 1 light harrow	1.0	1 man, 1 tractor, 1 cultivator	0.3	2 horses Harrow	.50 0.08	1 tractor Cultivator	.25 0.02
Blocking	——	——	1 man, 1 tractor	0.45	——	——	1 tractor Cultivator	0.36 0.03
Cultivating	1 man, 2 horses 1 cultivator	4.35	1 man, 1 tractor 1 cultivator	2.80	2 horses Cultivator	1.09 0.26	1 tractor Cultivator	2.10 0.17
Thinning	6 men	23.34	——	——	——	——	——	——

Hoeing	2 men	9.6	2 men	11.6	——	——	——	——
Irrigating	1 man	12.3	1 man	12.3	——	——	——	——
Pulling weeds	1 man	4.8	1 man	4.8	——	——	——	——
Lifting	1 man, 4 horses 1 puller	4.45	2 men, tractor harvester	6.0	4 horses Puller	2.23 0.44	Tractor Harvester	2.25 3.00
Topping	6 men	35.9	——	——	——	——	——	——
Loading, hauling	1 man, 1 truck	7.11	4 men, 2 trucks, 1 tractor, 1 loader	2.9	Truck	5.69	Trucks Tractor Loader	2.32 2.18 1.00
Totals Labor costs a $.50 per hour		119.02		47.45		$18.01 59.51		$22.93 23.72
Total costs per acre.............						$77.52		$46.65

*Data derived from large-scale tests in Colorado in 1942 and 1943.

as a whole so that the entire power, labor, and machinery program may be a smooth one. Certain phases of mechanization may require pooling of mechanical resources of two neighboring farms. For example, as a one-farm job, spreading manure is not only arduous but is time-consuming. Two neighbors could to advantage join forces for this operation. One tractor could be equipped with a power manure fork for loading one spreader, while the other tractor is pulling a spreader. In this operation both the spreaders should be rubber tired to make possible rapid movement to and from the field. The equipment cost, of course, would be greater than with the present practice. The hand labor is not only less arduous, but the time saved is very appreciable. Probably the most important advantage gained is that the operation can be more timely than with present methods. Naturally a grower will think twice before he will want to invest in the added equipment required to mechanize the operation of spreading manure but his time would have to be worth only 60 cents per hour to break even and he would have any advantage of the timeliness of the operation or benefits of lighter labor in addition.

After several years experimentation on mechanical thinning, in order to get a measure of the effect of a mechanized practice on the sugar beet crop, trials on a commercial basis were conducted in 1942 and 1943. Often a mechanical practice is difficult of scientific interpretation because the larger plot size that is necessary prevents setting up of replicated plots. In the 1942 and 1943 tests, the plots were laid out to fit the machine operations and were extensive enough to give sufficient acreage for time studies. Sugar beet fields large enough to afford replications for satisfactory analysis were chosen. The quality and quantity of the product was then measured by sampling cleaned beets.

Comparison between our present practice of producing beets and the proposed mechanized system is shown in Table 1. The data are based upon time studies conducted in Colorado in connection with these tests. It is evident that the cost in time or money for most of these operations will vary in different localities and with different degrees of skill of available labor.

As shown in Table 1, one of the most noticeable time-saving operations is that of mechanical thinning of beets. More than 20 man-hours per acre were saved. To mechanize this operation, it is not necessary to buy much additional equipment so that the total time saved in all the operations is very great and the total increased machinery and power costs are not materially greater than for present practice. Mechanical thinning has progressed to the point where it is a commercial practice. Comparative results on crop yields in the Colorado experiments in 1942 and 1943 are shown in Table 2.

Attention is also called to the very great saving of time from use of machines for harvesting. The developments in this field of agricultural engineering are extremely promising. Mechanical harvesting is nicely emerging from the experimental stage into the practical. Mechanical harvesters are now built that mechanically top the beets, place the tops in windrows for curing or for immediate transporta-

TABLE 2.—*Comparison of sugar beet yields obtained in Colorado tests in 1942 and 1943 with four types of thinning operations.**

Type of thinning operation employed	Comparative yields, %		Man-hours per acre, 1942
	1942	1943	
Hand blocking and thinning	100	100	23.34
Mechanical thinning, followed by trimming by long handled hoe	93.9	96.5	9.55
Thinning by long handled hoe only	94.9	97.6	16.20
Mechanical thinning, machine operation only	101.0	86.5	2.55

*Man-hours per acre as determined in 1942 are shown.

tion to stack or silo and place the beets in cleared windrows for mechanical or hand loading, both the tops and roots being so located that it is practical to load from the field without running over the windrows.

The mechanization of the operations involved in the production of such a crop as sugar beets is certain to raise several questions in the minds of the producers such as, "Can I afford the machinery?" "What will be the effect on the quality and quantity of the crop?" "How will such a program fit into my other farm operations?" "What will be the effect on the labor requirements?"

The four questions in the beet grower's mind can be answered definitely. He can afford the equipment necessary for mechanizing the production of the crop since he is going to save over $30.00 per acre by increasing his machinery costs less than $5.00.

The grower may, in some cases encounter reduced yields from mechanization, as evidenced by the 1943 data. His saving in dollars and cents by the mechanical methods may therefore be strongly decreased, but there is still on the credit side the freedom from the disadvantages of present dependence upon transient labor. There is also both mechanical and agronomic possibilities of improved technics to hold this loss to a small figure, or actually to give yields superior to those obtained by present hand methods.

The mechanized beet program can fit into the general farm plan to advantage as illustrated by the fact that the same power equipment is just as usable for other crops as for beets and has a decided advantage in making possible a year around constant labor use.

The mechanization of the beet crop has several direct results. some of which have post-war implications. The changing of the production of beets from a laborious hand and back-breaking operation to a machine job will aid in making it more tempting to the returning soldier. The elimination of need for transient labor will help to stabilize the farm job and especially is this true if the farm manager will organize his crop program so that his labor curve will be a more nearly smooth one throughout the year.

AGRONOMIC CONSIDERATIONS OF MECHANIZED SUGAR BEET PRODUCTION[1]

J. O. CULBERTSON[2]

THE present critical situation with respect to labor has resulted in greater demand for mechanization of sugar beet production, so that many procedures which were in process of evolution have suddenly been pushed forward. Great strides in mechanization of the industry have opened many new fields for agronomic investigation and have necessitated the evaluation of older agronomic information with respect to the new methods of production. The sugar-beet agronomists are not altogether unprepared to meet the challenge of complete mechanization, due to previous research that forms a workable basis for appraising the value of the new methods and furnishes a starting point for such new research as is needed.

During the war emergency, the sugar beet, like any other crop, must stand strictly upon its merits. It must produce human food by direct and indirect methods, in a manner economical with respect to labor and land used in its production. The present promise of almost complete mechanization offers hope of greatly increased efficiency in sugar beet production. It seems probable that, for some time after the war, there will be great demands upon all agriculturally productive areas to produce maximum food. Sugar, as an easily handled, highly concentrated food, may be important during this period of readjustment.

Each phase of mechanization presents problems that must be answered before the sugar beet crop can be produced at greatest efficiency. The important relationship existing between stand and yield will be discussed before considering the problems of mechanization.

STAND VS. YIELD

A major problem in sugar beet growing is the determination of the optimum stand of plants so that most economical use is made of the soil resources available. There has always been a certain amount of conflicting opinion as to what constitutes a satisfactory stand. Agronomists have shown that in many areas, at least, the more dense the stand, within reasonable limits, the greater the yield per acre, and the higher the sucrose percentage and purity of the beet. Growers, on the other hand, have not always been convinced that increased

[1]Contribution to the symposium on "Sugar Beets in the War and Post-War Periods" held at the annual meeting of the Society in Cincinnati, Ohio, November 10, 1943. Cooperative investigations of the Minnesota Agricultural Experiment Station and the Bureau of Plant Industry, Soils, and Agricultural Engineering, Agricultural Reseach Administration, U. S. Dept. of Agriculture. Paper No. 2145 of the Scientific Journal Series, Minnesota Agricultural Experiment Station. Received for publication February 28, 1944.

[2]Associate Agronomist, Division of Sugar Plant Investigations, Bureau of Plant Industry, Soils, and Agricultural Engineering. The writer wishes to thank Dr. G. H. Coons, Principal Pathologist, Division of Sugar Plant Investigations and Dr. H. K. Hayes, Chief of the Division of Agronomy and Plant Genetics, University of Minnesota, for suggestions and criticisms during preparation of this manuscript.

stand leads to increased yield, or that additional increase would more than offset the higher production costs. Increased stand density has been difficult to obtain in many instances because hand thinners have been unwilling to leave closely spaced plants. Mechanization may change this situation, since it may be as easy to space beets at 6-, 8-, or 10-inch intervals as at the customary 10-or 12-inch intervals, or even the 18-inch spacing used with check row drills.

Stand is composed of two major factors, first, the original allotment of soil surface allowed per plant as determined by the width between the rows and the spacing of the individual plants within the row, and, second, the number of blank spaces within the row. A good stand of beets at harvest time is one in which the original space allowed per plant closely approaches the optimum for the particular conditions under which the crop is produced, and which has a minimum of blank spaces in the row.

Considerable agronomic attention has been given to spacing trials. The results of seven trials in Minnesota conducted under conditions of natural rainfall are shown in Fig. 1.

These seven tests show a decrease in yield from 18.81 to 12.38 tons as spacing was increased from 16 × 8 to 22 × 20 inches.

Table 1 gives the results of four replicated tests grown under irrigation. Data given by Brewbaker and Deming (1)[3] and by Culbertson in 1932, are averages of four row widths of 18 to 24 inches. Data given by Robbins and Price (8) are for 20-inch rows only. In the 1933 tests by Culbertson three row widths of 18 to 22 inches were used.

As an average of the four tests, 8-inch spacing yielded 0.84 and 1.87 tons per acre more than 12- or 16-inch spacings, respectively.

Much of the work in other countries seems to indicate higher yield for closer spacing. Decoux, *et al.* (4) report trials on fertile soil in which two varieties were tested at stand densities varying from 26,000 to 101,000 plants per acre. For the variety with smaller foli-

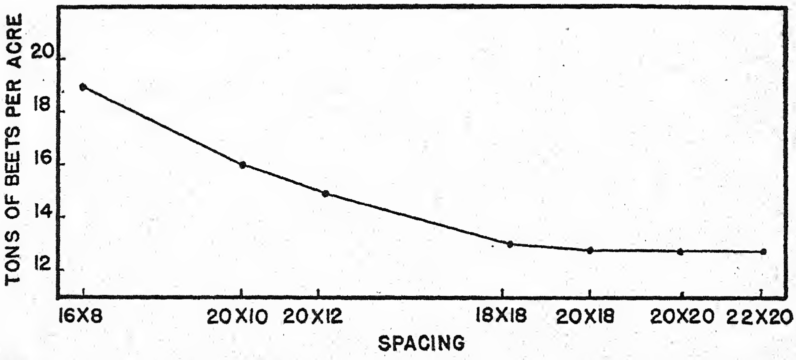


FIG. 1. The average acre yield of roots in tons from seven trials and seven space allotments, as obtained for row width and row interval shown. Data obtained from normally competitive beets and computed on basis of 100% stand for space shown.

[3]Figures in parenthesis refer to "Literature Cited", p. 565.

TABLE 1.—*Acre yields of sugar beets in replicated trials in which varying spacing intervals in the row were compared.*

Location of test	Reported by	Acre yields in tons for spacing of		
		8 inches	12 inches	16 inches
Colorado, 1931*	Deming and Brewbaker (1)	19.46	18.99	18.06
California, 1932†	Robbins and Price (8)	15.98	15.37	13.47
Utah, 1932*	Culbertson	19.77	20.28	19.78
Utah, 1933‡	Culbertson	18.39	15.58	14.74
Average		18.40	17.56	16.51

*Average of four row widths, 18, 20, 22, and 24 inches.
†Data reported are from 20-inch rows only.
‡Average of three row widths, 18, 20, and 22 inches.

age bouquet, there was a regular increase in yield from least dense to the most dense stand. However, the maximum yield was obtained at 81,000 plants per acre for the variety with the larger foliage bouquet.

Nuckols (7), however, has called attention to a possible fallacy in these spacing trials. He has shown that the usual method of selecting the "normally competitive" beet may favor unduly the closely spaced plantings since the effect of competition has not been entirely removed. These tests have taken into consideration the possible yields when perfect stands were obtained, a condition which never can be obtained in the field. With the advent of mechanization, agronomists will be interested in studying the effects of various spacing intervals as determined by mechanical means, taking yield upon a basis of the actual stand produced.

There is considerable evidence to show that the elimination of blank spaces or skips in the stand is of great importance in determining the final yield. Brewbaker and Deming (1) concluded that uniformity of stand, or the elimination of the skips, is more important than actual space allotment in determining yield.

As an average of five tests in growers' fields in Minnesota and Iowa, it was found that when a single beet was missing in a field planted 18 × 18 inches with a check-row drill, the surrounding beets recovered only 53% of the calculated loss in yield due to the missing beet. Thus, the loss was found to be 47% (2). Close relationship between stand and yield was shown in a test conducted at Waseca, Minn. (2). As an average of 5 years, using 10 replications each year, it was found that yield increased from 5.57 tons to 15.24 tons per acre as the stand increased from 22.2 to 100% of a full stand spaced 20 × 12 inches.

One only has to examine a number of growers' fields to observe the wide variation in the number of plants per acre at harvest time. Even when hill-drop or check-row planters have been used and the number of "hills" per acre determined thereby, considerable variation is found, not only between different fields, but even different parts of the same field. The difference between a profitable crop and failure often can be attributed to lack of sufficient stand to utilize efficiently the soil area.

Attention has been called to this relationship of stand and yield, since it seems probable that the agronomic considerations related to mechanization will be most closely associated with ability to produce and maintain the optimum stand by mechanized means. If sugar beets are to compete successfully with other domestic crops there can be no marked lowering of the number of plants per acre. Rather, it is to be hoped that the use of mechanical means of production may increase plant populations by elimination of some of the causes of poor stand.

The immediate problems of mechanization bearing directly on the broad problem of stand that are of particular interest to the agronomist may be summarized under two headings, *viz.*, problems related to the use of sheared seed, and problems of mechanical thinning.

PROBLEMS RELATED TO USE OF SHEARED SEED

The agronomic problems coming under this head concern themselves primarily with uniform deposit of the sheared seed at the proper rate and under conditions suitable for prompt, even germination.

Although proper preparation of the seedbed has always been important, it has especial significance when sheared seed is used. With the lighter planting rates employed, greater dependence is placed upon the individual plant, and the seedbed must be prepared so that all the plants have a uniformly favorable chance to develop normally. There would seem to be sufficient information, both experimental and observational, regarding preparation of seedbeds.

Seed treatments as a means of controlling seed-borne disease is probably more important for sheared seed than for whole seed, since greater dependence is placed upon the individual seedling. There is sufficient evidence to show that under many soil conditions an efficient fungicidal treatment will result in greater uniformity of seedling distribution and consequent greater uniformity of after-thinning stand, especially when mechanical thinning is employed. The results of tests conducted in Minnesota in 1942 and 1943 are given in Table 2.

TABLE 2.—*Effect of treating sheared seed upon the number of seedlings in 100 inches of row in three replicated trials.*

Location of test	No. of replications	No. of plants per 100 inches of row from		Increase from treated over untreated seed, %
		Untreated seed	Treated seed	
Waseca, 1942.....	3	12.0	17.5	45.8
Waseca, 1943.....	5	23.2	32.0	37.9
St. Paul, fall 1943	5	7.6	18.3	140.8
Average..........		14.3	22.6	

The data show the importance of treating sheared seed, since increased stands of 40% were obtained by treating seed planted at the normal time in the spring. The increase of 140% in stand as a

result of planting treated sheared seed in the fall possibly may be attributed to the fact that fungi causing seedling disease are more numerous or conditions are more favorable for their attack upon seedlings at that time.

The success of sheared seed depends upon the proper distribution of individual plants at thinning time so that single plants may be left in a majority of cases. The rate of planting sheared seed is of much greater importance than the rate of planting whole seed followed by old methods of thinning. The use of too much seed per acre will crowd the plants so closely that it may be impossible for mechanical thinners to do a satisfactory job of thinning, while too little seed will result in so thin a stand that mechanical thinning is impossible. Studies of planting rate must be made upon a basis of number of viable germs planted per unit of row, and the relationship between this planting rate and the distribution and density of the pre-thinning stand must be determined. Planting rates will also need to be adjusted for different varieties and even for different seed lots of the same variety, and possibly also for fertilizer application and the effect of the previous crop.

Preliminary results of rate of seeding in Minnesota were given by Culbertson (3). These data, together with results of further trials, are given in Table 3.

TABLE 3.—*Effect of rate of planting sheared seed upon the number of seedlings per 100 inches of row in three replicated trials.*

Location of test	No. of replications	Seed per acre, lbs.	No. of seedlings per 100 inches of row
Waseca, 1942	3	1.25	12.0
	3	2.5	23.0
Waseca, 1943	5	2.5	27.8
	5	5.0	32.0
	5	7.0	37.2
St. Paul, fall 1943	5	2.5	7.5
		5.0	13.5
		7.5	19.6

Kotila and Coons (5) have shown that use of fertilizers high in phosphate reduce damping-off of seedlings in the greenhouse. The use of generous applications of treble superphosphate have been found to increase stand of sugar beet seedlings under certain conditions in the field. As an average of 3 years' tests at Waseca, Minn., after-thinning stands of 46.7 and 51.5 plants per 100 feet of row have been obtained from unphosphated and phosphated plots, respectively. The difference, although small, was significant. Results with sheared seed obtained in the fall of 1943 were 15.5 seedlings per 100 inches of row when no fertilizer was used, compared with 18.1 seedlings when treble superphosphate was used at the rate of 250 pounds per acre.

It has been assumed that if the pre-thinning stand has 30 plant-containing inches out of a span of 100 inches of row, the stand is adequate for mechanical thinning. A test conducted in Minnesota in 1942 gave after-thinning stands of 64.4 and 81.0 plants per 100 feet of row when the pre-thinning stands had 10.2 and 17.2 plant-containing inches, respectively, out of each 100 inches of row. These stands were blocked and thinned with long-handled hoes.

Shallow planting where soil moisture is adequate for prompt germination, and in regions of little soil blowing, seems most desirable. Results of two depth of planting trials, one at Waseca in the spring and one at St. Paul in the fall, are shown in Table 4.

TABLE 4.—*Effect of depth of planting sheared seed upon number of seedlings per 100 inches of row in two replicated trials.*

Location of test	No. of replications	No. of plants per 100 inches of row from depths of		
		½ inch	1 inch	1½ inches
Waseca, 1943.........	5	45.5	32.0	24.2
St. Paul, fall 1943......	10	20.9	17.4	11.1

Shallow planting appears to favor early emergence, thus reducing danger of damage to the stand as a result of crusting.

The need of uniform seed distribution seems obvious. Bunching of the seed or long skips in the drill row will defeat the purpose of sheared seed. Seedbed preparation may be very important with respect to uniform distribution, since it is obvious that smoother working of the drill would result with consequent greater uniformity in seed placement.

PROBLEMS RELATED TO MECHANICAL THINNING

At thinning time the beet grower has the choice of several ways of thinning his plants. The most economical of time and labor is mechanical thinning. This may be done with any of the several machines devised for the purpose. When pre-thinning stands are adequate and properly spaced, it is possible to obtain very satisfactory after-thinning stands. If sheared seed is used, a high percentage of the blocks left by the mechanical thinner will contain single plants. As previously noted, present information indicates that when approximately one-third of the 1-inch intervals contain one or more plants, satisfactory stands can be obtained by mechanical thinning. Soil type may affect the operation of the mechanical thinner, since soils which tend to crust or to push may make it more difficult to leave the small blocks desired in mechanical thinning. Soil moisture and weed growth may also affect the operation of the thinner so that heavier stands are required under certain conditions than under more favorable circumstances.

Data on the effect of doubles and even multiple hills need to be reexamined with respect to mechanical thinning. Evidence presented

by Brewbaker and Deming (1) shows no loss in weight of doubles over singles and only a slight reduction in weight of the singles adjacent to doubles. Singles and doubles alternated gave approximately the same yield as singles alone. In a replicated test at Crookston, Minn., in 1940, using two varieties of beets, it was found that doubles did not differ significantly from singles in yield. Mervine (6) has reported a trial conducted in Colorado in which 30% of doubles left by a mechanical thinner did not produce any measurable effect upon the yield.

Planting on weed-infested land may present a serious problem when mechanical thinning is used, possibly requiring modification of practices, such as a relatively wide space between the plants within the row to permit cross cultivation. Thus, the plants in the final stand may need to stand at least 16 inches apart to permit cross cultivating. Such wide spacing will, no doubt, preclude the possibility of mechanical thinning since it will be necessary to leave a block sufficiently large to insure a plant in every place. These large blocks will have to be finished with long-handled hoes or by hand thinning. While the method of handling would be more expensive than mechanical thinning, it has been used successfully in the humid area, notably in the Red River Valley of Minnesota and North Dakota. Any reductions in yield as a result of wide spacing have been more than repaid by elimination of late planting of a portion of the crop when hand labor was used for blocking.

Stands which are found inadequate for either mechanical thinning or cross blocking often may be sufficiently good to produce a good yield if carefully hand blocked. This can be done satisfactorily with a long-handled hoe if sheared seed has been used.

General methods of weed control are well known, but there are special technics that need further investigation, especially for the humid area. One of these is date of planting. It has been demonstrated that early planting produces larger yields than moderately late planting. However, there is appreciably less trouble with weeds when planting is delayed sufficiently to permit one additional working of the ground to destroy an additional crop of weed seedlings. Careful studies in the saving of labor cost *vs.* reduction of yield associated with delay in planting need to be made to determine the feasibility of adjusted planting dates where weed infestation may be unduly serious.

It has been the practice in the Red River Valley in Minnesota and North Dakota to plow under a crop of sweet clover in June or July keep the ground fallow, and plant sugar beets the following spring. This has permitted early planting with a minimum of weeds. No doubt, many factors, such as moisture conservation, weed control, possibility of early planting, and improved soil fertility and tilth, have contributed to the success of this practice. Growers having higher priced land or in areas of heavier rainfall have hesitated to use fallow since it would mean the loss of a crop year. However, the possibilities of increased yield and reduced cost of production, especially in the humid area, make this practice worthy of test in other areas.

DISCUSSION

Expansion of sugar beet acreage has always been hampered by the large amount of seasonal hand labor required, particularly in thinning and harvesting. There seems to be little question but that mechanization of sugar beet production will eliminate or reduce much of this seasonal labor requirement so that beets can compete more successfully with other commonly grown farm crops. Sufficient evidence is at hand to formulate a sound working basis for the production of the crop with extensive use of machines to replace hand labor. Details will need to be filled in, but with the large number of workers engaged in studying the various phases of the problem, it should not be long until mechanization of sugar beet production is widely accepted. There is reason to believe that the savings in labor resulting from mechanization may bring about a revolution in sugar beet production which may, in some respects, be comparable to that obtained in small grains by the development of the reaper, binder, and combines. If such is the case, there need be little concern over future expansion of sugar beet growing, since beet sugar can in all probability be produced with much more efficient use of man and machine power.

LITERATURE CITED

1. BREWBAKER, H. E., and DEMING, G. W. Effect of variations in stand on yield and quality of sugar beets grown under irrigation. Jour. Agr. Res., 50:195–210. 1935.
2. CULBERTSON, J. O. Sugar beet culture in Minnesota. Minn. Agr. Exp. Sta. Bul. 349. 1940.
3. ————. Segmented sugar-beet seed. Minn. Agr. College Ext. Bul. 240. 1943.
4. DECOUX, L., VANDERWAEREN, J., and SIMON, M. Le nombre maximum de betteraves a l'hectare. Pub. de L'Institut Belge pour L'Amélioration de la Betterave, 3:175–193. 1935.
5. KOTILA, J. E., and COONS, G. H. *Aphanomyces* root rot of sugar beets as influenced by phosphate application. Proc. Amer. Soc. Sugar Beet Tech., Part II, 223–225. 1940.
6. MERVINE, E. M. Labor saving by beet mechanization. Through the Leaves, 30:Nov.–Dec., 7–10. 1942.
7. NUCKOLS, S. B. The use of actual and competitive yield data from sugar beet experiments. Jour. Amer. Soc. Agron., 28:924–934. 1936.
8. ROBBINS, W. W., and PRICE, CHARLES. Sugar beet production in California. Calif. Agr. College Ext. Circ. 95. 1936.

VARIABILITY IN THE SPECIES *BETA VULGARIS* L. IN RELATION TO BREEDING POSSIBILITIES WITH SUGAR BEETS[1]

F. V. OWEN[2]

THE species of beets known as *Beta vulgaris* L. includes sugar beets, mangel wurzels, red table beets, and Swiss chard. For practical purposes most forms of the wild beet, *B. maritima* L. might also be included, because most all these beets cross readily with the domesticated varieties. This represents a great range of variability. Much variability also exists within varieties. The extent of this genetic variability accounts for the success of previous efforts in applied breeding work, and it indicates the existence of a valuable source of biological material that may be molded into more valuable forms in the future.

While recognizing this genetic variability, an equally great source of environmental variability must also be considered. Beet development is so strongly dependent upon environmental conditions that a study of heredity and environment must go together.

It should not be implied, however, that environmental variability always represents a handicap in connection with breeding work. When properly understood and controlled, environmental influences may constitute an invaluable aid to the breeder. This point may be illustrated by relating some experiences in breeding beets for resistance to the virus disease known as curly-top. Twenty-five years ago the possibility of producing curly-top-resistant varieties of sugar beets was something that nobody was too sure about. Progress was slow at first and improvements in degree of resistance were small. By 1928, Carsner, *et al.* (3)[3] had brought together several strains with slight to moderate degrees of resistance. In 1929 the important decision was made of mixing all of these strains together. The resulting mixed variety was designated U. S. 1. The significant thing about this heterogeneous material from the geneticist's viewpoint was the occasional appearance of what seemed to be highly resistant individual beets. Back in 1930 and 1931 it was not known whether these outstanding individual beets were really as resistant as they appeared, whether they escaped infection altogether, or whether they were influenced in their growth by some special environmental factors. It was eventually learned that their development was affected by both environmental and heritable influences.

More recent progress with curly-top resistance has been most significantly affected by a better knowledge of the environmental variability. It was learned that young beets were more easily infected

---

[1]Contribution to the symposium on "Sugar Beets in the War and Post-War Periods" held at the annual meeting of the Society on Cincinnati, Ohio, November 10, 1943. Received for publication February 28, 1944.

[2]Geneticist, Division of Sugar Plant Investigations, Bureau of Plant Industry, Soils, and Agricultural Engineering, Agricultural Research Administration, U. S. Dept. of Agriculture.

[3]Figures in parenthesis refer to "Literature Cited", p. 569.

than older beets and that the disease became more severe in hot weather than in cool weather. This information has made it possible to establish drastic curly-top exposures in midsummer plantings.

These drastic exposures have been found to have a profound effect upon selection and evaluation work. Under mild or only moderately severe exposures, curly-top resistance has the appearance of a dominant character. When hybrids between resistant and susceptible types were tested under the less drastic environments, the F_1 plants resembled the resistant parent (1). Under the more drastic exposures now made possible by midsummer plantings, dominance is lacking, and the F_1 hybrids resemble the susceptible parent much more than the resistant parent. Hence, the character might now be regarded as recessive rather than dominant. When selections were made under the less drastic environments where the F_1 hybrids could not be distinguished, segregation for relatively susceptible types were expected in the next generation. Under the more severe curly-top exposures, heterozygous individuals can be detected and eliminated.

A study of environmental variability is equally important in connection with breeding for resistance to any of the other beet diseases. Such studies are particularly significant in connection with breeding for increased resistance to bolting. Progress is impeded in connection with breeding for increased yield or sugar percentage because so little is known about controlling environmental variability.

The mechanization of harvest operations raises new problems and no doubt the breeder can be helpful, but there are likely to be disappointments if environmental variability is not fully recognized. Perhaps the most important thing the breeder can do is to increase genetic uniformity. It will take work to produce varieties of beets with uniformly shaped roots and with uniform crowns and foliar growth, but there are definite indications that this goal can be accomplished.

Genetic variability is also important in connection with characters that might be designated as breeders' tools. These characters do not affect yield directly, but they determine to a large extent what a breeder can plan to do in the way of developing breeding methods. One of the most convenient tools consists of a simple hypocotyl color character commonly used for a marker. In hybridization work the use of this character makes it possible to plan systems of matings whereby desired hybrids can be distinguished from other offspring which may not be hybrids.

Beets are especially variable with regards to sterility and incompatability relationships. Most sugar beets are inclined to be strongly self sterile, unless one provides an environment to induce selfing. Highly self-fertile types of beets exist, however. A type of self fertility found in one of the early curly-top resistant varieties appears to be determined by a single gene. With a knowledge of the rules of the oppositional hypothesis, this gene for self fertility can be readily transferred to any material where it is desired (4). This high degree of self-fertility is even more noticeable in the vigorous F_1 hybrids than in the less vigorous beets obtained after selfing.

Male sterility may become another important breeders' tool. It

facilitates hybridization work, and for this reason it is useful in connection with many types of investigations. There are different types of male sterility in beets, but the most useful type appears to be one produced by cytoplasmic inheritance. After selecting against genes that have a modifying effect, the inheritance of this type of male sterility follows the simple rules of maternal inheritance. Bv successive back-crossing the male-sterile equivalent of most varieties and of most inbred lines can be established. This cytoplasmically-inherited male sterility produces emasculation of flowers on a grand scale. If the male parent has been selected against the modifying genes, whole populations of infinite size may be completely male sterile. In the work with curly-top-resistant varieties the male-sterile equivalents of some of the best strains have now been established, but any thought of commercial utilization will depend upon further research, especially with breeding methods.

The knowledge of past success in breeding work adds confidence, but it is still difficult to look into the future and predict what may be done to establish a desirable character that appears to be practically non-existent.This is the present situation in this country with regards to prospects of developing unilocular biotypes of beets with single-germed seed balls. All of the present commercial varieties of sugar beets bear multilocular or multiple-germed seed balls, and this adds greatly to the task of thinning. The new and popular technic of shearing or splitting the seed balls into single-seeded portions, represents an artificial approach to the problem. It would seem that this artificial method should be considered only as a temporary answer, and the sheared, or segmented, seed might best be regarded as a victory model.

The problem of selecting for single-germed beet seed was popularized in this country a generation ago, but the work met with discouragement and was discontinued. A report of Russian work published in 1941 (2) seems to be the most encouraging news and indicates highly significant progress, as follows: "In the U.S.S.R., breeding work for the production of unilocular or single-germ varieties was originated by the Glav-Sakhar Breeding Station. In 1934 examinations were made in a large number of sugar beet seed fields and individual plants were selected from those in which all or most of the seed balls were unilocular. The seeds collected from such plants constituted the original material used in our work. The character for single-germ seed is under ordinary conditions recessive. In the F_2 generation, the plants segregate into types with unilocular and multilocular seed-balls. The unilocular types were characterized by vigorous vegetative development and a peculiar type of seed bush. (Data are given showing a strong but not complete correlation between the unilocular character and an extreme non-bolting tendency.) While the number of seeds in a seed ball is found to vary greatly in ordinary beet varieties, depending upon environment, the new unilocular varieties are very constant. We were not able to change the number of flowers in the unilocular types of plants although we varied our dates of planting, nutrition, environment (both outdoor planting and green-

house). *We have thus produced lines of sugar beets which are constant for the character of single-germ seed.*"

In searching for biotypes with unilocular seed balls, the hope of utilizing the wild beet, *B. maritima*, may not be promising because so far as is known it produces multilocular seed balls, the same as those of the domesticated beet varieties. However, unilocular seed balls are produced by other wild species. *B. lomatogona* produces unilocular seed balls and it has been hybridized with sugar beets. The F_1 offspring have been strongly sterile, but hope from this work should not be abandoned. If other methods fail in the search for unilocular types of beets, extensive X-ray work could well be attempted to increase the possibiltiy of a mutation that might be utilized.

LITERATURE CITED

1. ABEGG, F. A., and OWEN, F. V. A genetic factor of curly-top disease resistance in beets (*Beta vulgaris*, L.) and linkage relationships. Amer. Nat., 70:36. 1936.
2. BORDONOS, M. G. Unilocular types of sugar beets (sugar beets with single-germ seeds). Proc. Lenin All-Union Acad. Agr. Sci. U.S.S.R., 11:3–4. 1941. [In Russian. Translation by Eugenia Artschwager. On file at Bureau of Industry Library, U. S. Dept. of Agriculture.]
3. CARSNER, Eubanks, *et al.* Curly-top resistance in sugar beets and tests of the resistant variety U. S. No. 1. U. S. D. A. Tech. Bul. 360. 1933.
4. OWEN, F. V. Inheritance of cross- and self-sterility and self-fertility in *Beta vulgaris*. Jour. Agr. Res., 64:679–698. 1942.

ADAPTATION OF THE SUGAR BEET TO MEET THE NEEDS OF THE SUGAR INDUSTRY IN AMERICA[1]

H. E. Brewbaker[2]

THE beet sugar industry in America was entirely dependent on European sources of seed for its early development. The varieties then available were developed largely by commercial concerns; and although they were the result of intensive breeding work in producing yield, intermediate and sugar types, the selection work was done in Europe (12)[3]. It is not surprising, therefore, that these types, or commercial brands, failed to meet the specific needs of the American grower and sugar industry.

It is pertinent to record that, except for limited cooperative breeding strain tests in this country as early as 1925, the only serious attempt by any European seed producer to meet the specific varietal problems of the American industry was initiated at Brush, Colo., in 1934 and terminated in 1938.

During the first World War the American beet industry was faced with the heavy burden of providing seed for a quickly expanded acreage. Costly attempts were made to develop a domestic seed industry. This war-time seed emergency, coupled with the fact that sugar beet growers in America had been faced for years with two major diseases, namely, curly-top for the areas principally west of the Continental Divide, and leaf spot, *Cercospora beticola*, east of the Continental Divide, focused attention on breeding for varietal improvement and commercial seed production. The development of a self-sufficient domestic seed industry, largely by the overwintering method, as reviewed by G. H. Coons (4, 5), provided the final step needed to effectuate the improvement work in the United States by federal, state, and research agencies of the beet sugar companies.

In the history of plant breeding the development of curly-top-resistant varieties of sugar beets will rank among the important contributions. The curly-top disease is caused by a virus carried by the beet leaf-hopper, *Eutettix tenellus*. It was the principal cause of average yields (3) as low as 1.0 and 1.4 tons, respectively, for the years 1914 and 1919 in the California district, and 5.5 and 6.0 tons, respectively, for the years 1924 and 1926 in southern Idaho. Such low yields, which represent losses of from 60 to 90%, were leading to almost complete abandonment of factories in areas subject to frequent epidemics of this disease. The moderately resistant variety U. S. 1, released to growers in 1934, provided the first positive relief against this disease, seed being available that year for about 35,000 acres of commercial beets. Since that time, continued improvement has been made by the Bureau of Plant Industry, Soils, and Agricultural Engineering,

---

[1]Contribution to the symposium on "Sugar Beets in the War and Post-war Periods" held at the annual meeting of the Society in Cincinnati, Ohio, November 10, 1943. Received for Publication February 28, 1944.

[2]Agronomist and Plant Breeder, Great Western Sugar Company, Longmont, Colo.

[3]Figures in parenthesis refer to "Literature Cited", p. 574.

with further releases of U. S. 33, U. S. 34, U. S. 12, U. S. 15, U. S. 22, and U. S. 23. The Amalgamated Sugar Company also introduced their resistant variety, A600. Some of the recognized defects in U. S. 1, including a strong bolting tendency, were improved and resistance to curly top and ability to produce were improved in the later U. S. releases. Mass selection methods have been used extensively in making these striking improvements. Immunity from this disease apparently is not shown in any of the varieties, but a high degree of resistance has been obtained and still greater curly-top resistance may be achieved.

Leaf spot is less drastic in its immediate effects on the sugar beet than curly top; and for this reason, perhaps, popular demand for leaf-spot resistant varieties was less insistent. Nevertheless, this disease may, under weather conditions that favor epidemics, result in a loss of from 25 to 40% in total sugar production. Heritable resistance to leaf spot was found in individual plants existent within commercial European brands and in *Beta maritima* L., a closely related wild type which hybridizes readily with the commercial type, *Beta vulgaris* L.; and much progress has already been made in developing commercially acceptable varieties which are highly resistant. Two varieties (6, 7) have already been released by the Bureau of Plant Industry, Soils, and Agricultural Engineering to meet this problem, namely, U. S. 200 × 215, and U. S. 215 × 216, both of which represent open-pollinated hybrids of two inbred strains. U. S. 200 × 215 when compared with "Synthetic Check", which is a first generation increase of a mixture of 9 European brands, in a total of 83 replicated trials from 1938 to 1942 in many sugar beet districts east of the Rocky Mountains exceeded Synthetic Check by 4.7% in total sugar production as an average of all tests. Included in these tests were some in which leaf spot was a limiting factor and in such cases the difference was greater in favor of U. S. 200 × 215. Over this same general area the more resistant hybrid ,U. S. 215 × 216, produced 5.2% more sugar per acre than U. S. 200 × 215 in 26 replicated trials in 1941 and 4.5% more in 21 similar trials in 1942. In 40 similar tests for the same two years U. S. 215 × 216 showed an increase of 8.4% in sugar per acre over Synthetic Check (9).

Much of the breeding work of the American Crystal Sugar Company in recent years has been directed toward the development of varieties resistant to leaf spot. Unpublished data from four replicated trials in the Arkansas Valley of Colorado in the past two seasons show the resistant variety American No. 1, outyielded Schreiber S. S. (European) by 5.75% in root weight, 25.07% in sugar content, and 34.1% in total sugar production. These results were obtained under conditions in which the leaf-spot epidemic was "prolonged and severe."

Breeding work by the Great Western Sugar Company, which was started in 1910 and continued extensively to date, particularly since 1925, resulted in adapted varieties which showed a progressive increase in production, particularly during the earlier generations of family selections (1, 8). The variety GW59, which originated out of this long period of breeding work, showed an increase of 10.8% in yield

of sugar per acre over the Great Western Standard variety GW18 for the 4-year period of 1939–42 at Longmont, Colo., and GW18 exceeded the best of four leading European brands at the same station for the 4-year period of 1934–37 by 4.9% in total sugar production. This constitutes a rather outstanding example of varietal adaptation. GW 18 is very susceptible to leaf spot and GW59 possesses only a mild resistance to the disease. More recent work has been directed mainly toward the development of high resistance to leaf spot in combination with other essential characters and certain highly resistant numbers have been extensively increased for commercial use.

With the many contributions to leaf-spot-resistant commercial varieties it appears to be only a matter of a few years at the most until the losses from this disease will be greatly alleviated. With this disease, as with curly top, prospects of attaining immunity seem doubtful. More recent work, however, indicates that near-immunity may be achieved.

Breeding work by the Holly Sugar Corporation has been centered largely on agronomic improvement.

These examples have been chosen to represent some of the more outstanding American contributions directed toward elimination of certain hazards in growing sugar beets and general improvement in the commercial varieties available to the American grower.

While much progress has been realized in breeding the sugar beet to meet specific American needs, the job is far from finished. No doubt, much further improvement lies ahead in the fields of breeding for resistance to the two principal diseases, curly top and leaf spot, in combining resistance to these two diseases into one variety, and in breeding for resistance to other diseases, particularly Fusarium yellows (2). There is some evidence which indicates improvement may be made by breeding for resistance to Rhizoctonia and damping-off in seedlings, while immunity to rust, *Uromyces betae*, is clear cut in segregating generations and presumably could be incorporated into homozygous immune strains.

Resistance to cold has been shown by tests in northern Colorado to be a heritable character, subject to improvement through selection. Plantings made in August for seed production the following year occasionally suffer severe winter injury. One or two mass selections for cold tolerance under these conditions have increased that tolerance measurably. It remains to be determined whether this cold tolerance will also be exhibited as resistance to frost injury in the seedling, making earlier plantings and consequently longer growing seasons possible, or in the mature plant which would permit of later development in the fall.

Seed-producing capacity varies greatly between commercial varieties, some of the very excellent producers of roots being rather mediocre to poor seed producers. This constitutes a problem of immediate concern to the sugar beet breeders. Rapid improvement might be anticipated since little previous work has been done along this line.

In breeding for higher seed-producing ability extreme care must

be taken to avoid undue multiplication of types which are heavy seed producers simply because they are rapid bolters in the seed field, which in turn might lead to an undesirable bolting tendency in commercial fields of beets. Results obtained in tests at Riverside, Calif., in 1940–41 from October 15 plantings were supplied by Dr. Eubanks Carsner as follows: Seed of GW18 produced in Colorado showed 3% bolting on May 13, 1941, as compared with 16% and 29% for seed of the same variety grown from plantings made at Mesa, Ariz., on August 23 and October 7, 1939, respectively; also seed of U. S. 200 × 215 grown in Oregon produced 24% bolters as compared with 52% for seed of the same variety produced in Arizona. Because of this natural selection tendency commercial seed increases in Arizona are generally limited to one generation from stock seed.

In looking toward eventual mechanization of the beet crop it seems probable that the plant breeders will also be called on to provide varieties with a high degree of uniformity of root type as contrasted with the generally heterogenous mixtures of types which characterizes nearly all of the commercial varieties being grown extensively at the present time. Serious attention will need to be directed toward the elimination of individuals characterized by excessivley large or high crowns. The role which the environment plays in affecting root type is discussed in the paper by F. V. Owen in this symposium (pages 566 to 569). It may be observed, however, that such characters as shape of root and the development of undesirably heavy secondary roots, including "sprangling," will probably continue to vary considerably with varying soil conditions regardless of the extent of anticipated genetic improvement for these characters.

The sugar beet industry is in a position of utilizing any improved varieties immediately since the processor provides all seed to the sugar beet grower. There has always been, therefore, an urge upon research to provide those improvements which could be quickly utilized.

Much has been accomplished already in a study of fundamental principles, particularly in relation to curly top and other diseases, and the inheritance of resistance to curly top and other characters. Various breeding methods are employed by different breeders, inbreeding being depended upon by some while broader family or mass selection methods have been employed very successfully by others. Breeding work has been greatly stimulated and rendered increasingly productive as a result of such improvements as overwintered seed production, photothermal induction of seed stalk production in the greenhouse, and planting of seed in the Southwest with later shipment of the stecklings to the north for seed production, all of which operate to reduce a normal 2-year program of seed production down to one generation a year. These fundamental principles and breeding methods are working tools for the plant breeder. Significant progress in varietal improvement has already been made and further progress can undoubtedly be made without some of these tools, but further intensive cytogenetic and fundamental physiologic investigations are needed to provide certain principles basic to the program.

Except for those characters already mentioned, particularly uniformity of agronomic type of root including special emphasis on small crowns, it seems doubtful if the present or post-war needs will demand much change of emphasis on the type of root which plant breeders are working for today. Single germ seeds will be most desirable if this character can be secured and incorporated into the present commercial varieties, the possibilities of which are discussed by Doctor Owen. Breeding methodology will probably move toward more inbreeding, especially if greater uniformity of type becomes an essential. Self-pollination methods are slow and subject to the obvious difficulties associated with a high degree of self-sterility, even under the most favorable conditions, loss of production for most inbreds, and lack of pollen control in making subsequent hybrids of inbred lines, but these difficulties are not insurmountable and only mean greater effort to accomplish the desired progress. Multiple-cross and back-cross technics offer possibilities for use of inbreds. It has been found true for corn in work by Jenkins (10) that inbred lines with the highest yield genotype are the descendents of foundation plants of comparably high yield genotype. Based on this principle, a method whereby open-pollinated seed from highly selected individuals which were grown together in an isolated group is used to test the fundamental genetic capacity of the individual mother to produce, following which self-pollinated seed from the best producers would be recombined immediately, offers some opportunity for breeders to make progress for several characters and at the same time to hold or increase yielding ability and to induce greater uniformity than would be possible by the broader family or mass selection methods.

It seems probable that the development of varieties which are streamlined to meet the needs of the sugar beet grower in a mechanized cultural practice is the immediate job ahead for those interested in varietal improvement.

LITERATURE CITED

1. BREWBAKER, H. E., and MCGREEVY, B. F. A critical study of family and group breeding methods for sugar beets. Proc. Amer. Soc. Sugar Beet Tech., 1938:42–50. 1938.
2. BOCKSTAHLER, H. W. Resistance to Fusarium yellows in sugar beets. Proc. Amer. Soc. Sugar Beet Tech., 1940: 1:191–198. 1940.
3. CARSNER, Eubanks, *et al.* Curly-top resistance in sugar beets and tests of the resistant variety U. S. 1. U. S. D. A. Tech. Bul. 360. 1933.
4. COONS, G. H. U. S. sugar beet seed meets war crisis. Sugar, 38, No. 1:18–23; No. 2:22–28. 1943.
5. ————. Improvement of the sugar beet. U. S. D. A. Year Book, 1937: 625–657. 1937.
6. ————, and STEWART, DEWEY. U. S. 200 × 215, a new sugar beet variety resistant to leaf spot. The Sugar Jour., 3:7–8. 1940.
7. ————, ————, and GASKILL, JOHN O. A new leaf-spot resistant beet variety. Sugar, 36, No. 7:30–33. 1941.
8. DAHLBERG, H. W., MAXSON, A. C., and BREWBAKER, H. E. Breeding for resistance to leaf spot and other characters. Proc. Amer. Soc. Sugar Beet Tech., 1940: 1:169–180. 1940.
9. GASKILL, JOHN O. Sugar-beet leaf spot is being controlled through breeding of resistant varieties. Colo. Farm Bul., 5, No. 5: 10–13, 1943.
10. JENKINS, MERLE T. Inbreeding and selection. Iowa State College Jour. Sci., 9:429–450. 1935.

11. OWEN, F. V., *et al.* Curly-top-resistant sugar-beet varieties in 1938. U. S. D. A. Circ. 513. 1939.
12. SKUDERNA, A. W., *et al.* Evaluation of sugar beet types in certain sugar beet-growing districts in the United States. U. S. D. A. Circ. 476. 1938.

SUGAR BEETS IN THE WAR AND POST-WAR PERIODS FROM THE STANDPOINT OF THE BEET SUGAR INDUSTRY[1]

A. W. SKUDERNA[2]

IN projecting the role of the sugar beet in the post-war period, the need for forward planning is at once apparent. This industry, a veritable infant among agricultural crops grown in the United States, has demonstrated a remarkable ability to live through periods of economic stress and ofttimes unfriendly political attitudes. With it all, it has become through the years a part of the community pattern of life where the crop has been grown during the last 25 to 50 years. This is not surprising when the value of the crop to the community is understood, and when the background of the industry is examined.

PRESENT STATUS OF THE INDUSTRY

The entire normal domestic beet acreage of approximately 1,000,000 acres grown in 1942 was only 0.3% of the total cultivated farm acreage in the United States. Yet, this small acreage produced almost 30% (32,327,342 100-pound bags of sugar) of our 1942–43 national consumption of sugar and was widely used in 43 of the 48 states, as well as in Alaska and the District of Columbia. This is indeed a rapid stride for an industry which began experimentally here about 100 years ago, and became first commercially established some 60 years back on a small scale and blossomed into much larger scale production only 40 years ago. Approximately 80 beet sugar factories process sugar beets into sugar during normal times, serving a beet-growing industry located in 19 states and a beet-growing clientele comprising some 100,000 farmers.

From standpoint of food production the sugar beet crop is one of the most efficient producers of food that is known among cultivated crops. On the same soil, sugar beets produce two major crops—sugar and forage. A 14-ton-per-acre crop of sugar beets produces about 3,700 to 4,000 pounds of sugar, or a food value of approximately 7,000,000 calories. This total is augmented by such by-products as beet tops, pulp, and molasses. The by-products from a 14-ton-per-acre yield of beets has a feed replacement value equal to a 60-bushel corn crop (6).[3] When fed in a balanced ration these by-products from 1 acre of beets will produce approximately 300 pounds of beef (10). In addition to the use of beet by-products for livestock feeding, beet molasses now is being extensively used in the manufacture of citric acid, yeast, and glutamic acid. Lime, a by-product from the refining process, is also used in several areas for improving soil texture and correcting soil acidity. In the post-war period, use of these by-products in plastics and other products is envisioned.

[1]Contribution to the symposium on "Sugar Beets in the War and Post-War Periods" held at the annual meeting of the Society in Cincinnati, Ohio, November 10, 1943. Received for publication February 28, 1944.

[2]General Agriculturist, American Crystal Sugar Company, Denver, Colo.

[3]Figures in parenthesis refer to "Literature Cited", p. 582.

Sugar beet production is concentrated in localized areas within regions having a mean temperature of approximately 70° F during the growing season. The location of sugar beets within regions is influenced by competitive crops, available labor supply, and moisture, soil, and climatic conditions. In more recent years, utilization of warmer areas, notably the Imperial Valley and San Joaquin Valley in California, has been successfully effected through timely plantings which make it possible to grow and harvest the crop before onset of hot weather. Extending the length of growing season through earlier planting of the crop has done much toward increasing the tonnage yield of beets per acre throughout all of the sugar beet producing areas.

Since sugar beets are grown under a wide range of soil, climatic, and cultural conditions in the widely separated districts of the 19 states where the beet sugar industry is located, the problem of developing adapted types of sugar beets best suited for each area is apparent. In some areas certain diseases of beets prevail, the control of which is conditioned, in part, by disease resistant varieties (9). That this has been recognized at an early date is easily verified from a brief search of literature on the subject with reference to establishment of sugar beet breeding work in this country (3). With the stimulus given beet breeding work through the development of the U. S. No. 1 curly-top resistant variety (2) and the successful utilization of the overwintering method of producing beet seed (4), several of the larger beet sugar companies merged their efforts in seed production. This led later to the establishment of the Western Seed Production Corporation, operating in Arizona and New Mexico. More recently, the West Coast Beet Seed Company was formed, comprising all of the beet sugar companies in the United States and having as its operating bases certain areas in northern and southern California, Oregon, and southern Washington. These two companies, together with individual enterprises of several of the beet sugar companies' beet breeding establishments, have produced, on an average, 14,000,000 pounds of seed annually over the last 7-year period 1937–43, inclusive. This is more than enough to meet the domestic requirements, with the result that nominal quantities of this seed have been exported to other countries.

Since the establishment of the beet sugar industry in this country, changes have occurred in the technology and labor requirements in production of other crops, and these changes have affected also the production of sugar beets. Foremost among these has been the introduction and general adoption of the farm tractor. Improved equipment for preparing the seedbed, planting, and cultivating is now available for use with various tractors. If tractors were selected with a view to labor economy alone, the labor required in seedbed preparation would be reduced by approximately one-half. To demonstrate possible savings in labor when the entire operation of sugar beet culture is mechanized, time studies were made on an experimental acreage, with the result that 47.45 man-hours were required per acre for the entirely mechanized practice as compared to 119.02 man-

hours for the standard practice of growing and harvesting an acre of sugar beets.

Concerning agricultural migratory labor recruited for the beet-growing areas year after year, this labor is usually thought of as "sugar beet labor". It is a fact, however, that these laborers work only in sugar beets from about May 15 to July 15, then do other agricultural work in the summer and return to sugar beets about the first week in October. The crops worked by this labor during the summer are not only general field crops, but those pertaining to the canning industry as well. The labor requirements of these other crops are such that they can and do use a greater amount of this migratory agricultural labor than is actually used in sugar beet production. Therefore, full mechanization of the sugar beet crop is bound to result in serious dislocations in availability of agricultural labor previously supplied through sugar company efforts for tending of the beet crop, and which labor has been largely used between the sugar beet thinning and harvesting periods for work in other agricultural crops.

As projected in this symposium, the objective of the "revolution in beet agriculture" now in progress is to eliminate hand work entirely, except for its casual use in hoeing operations. A large contributing factor to this "revolution" has been the development of the principle of processing multiple germ beet seed balls into prevailingly single germ segments (1). Through the development of modified planter equipment, it has been possible to plant at least 300,000 acres of beets with segmented seed this year, with an estimated saving in labor amounting to about 3 million man-hours.

COOPERATIVE ASSISTANCE OF TECHNOLOGISTS REQUIRED

AGRICULTURAL ENGINEER

In bringing to a reality complete mechanization of the sugar beet crop on a large scale (which the beet sugar industry feels is necessary to survive post-war competition), it must have the sustained interest and cooperation of the agricultural engineer. It is true that rapid strides have been made in partial mechanization of the beet crop, especially as it relates to use of segmented seed, modified planter units, blocking equipment for reduction of hand labor in thinning of the crop, and in loading of the topped beets, thus practically eliminating one of the most arduous tasks in sugar beet culture. However, the surface has only been scratched, and a great deal of work is necessary to evolve and develop certain equipment vitally needed in this program of mechanization.

Assuming that the development of single-seeded varieties is still a matter of years of research, a partial substitute must continue to be found in some form of machine which will efficiently produce, without too great injury to the embryo, single seed segments from multiple germ beet seed. The whole principle of seed shearing needs re-examining, both as to methods involved, abrasive materials used in the segmenting operation, size of segments most productive of single seed, and the use of specialized milling equipment for improving the quality of seed and the resultant germinating stands to meet more nearly the critical requirements of complete mechanization.

Then, too, a drastic overhauling of ideas concerning planter equipment is necessary. In a large part, the same type planters are now being used as at the turn of the century. Introduction of segmented seed requires planter units which are more precisely machined so that grinding of seed during the operation of planting will be avoided and a more positive delivery to insure proper spacing of seed and freedom from scatter in the row obtained. The industry visualizes the planter of the future as one that is built close to the ground, tractor-mounted, having a greatly improved seed-planting mechanism, and capable of doing precision work on a field scale basis. Steps have already been taken by the industry to acquaint the implement manufacturers of future needs, and the services of the agricultural engineer will be most helpful in guiding this development.

The equipment used in either down-the-row blocking of beets or cross-blocking and possible cross-cultivating to eliminate hand thinning, is susceptible to considerable improvement both in ease of operation and greater flexibility in adjustment of tools. To reduce or eliminate hand work altogether, study should be given to improve types of cultivator tools and use of better material in their construction. The hand labor requirements in thinning and / or hoeing beets represents approximately 27% of the total man-hours in growing an acre of beets (7), and therefore any improvement in equipment in this regard is significantly worth while.

Beet harvesting equipment presents still another problem. The variable cut finder principle is certainly the most effective method of topping beets in the ground; and from personal observation and reports covering the performance of more than 50 such harvesters this fall the conclusions are the same, namely, machine-topped beets are at least equal to hand-topped beets in quality of work. The separation of topped beets from clods is another matter, and where labor is available to do the job of sorting beets from clods, a considerable economy in cost of harvesting beets is effected. Where labor is not available for this work, it is obvious that some mechanical means of separating beets from clods is required. This is receiving the attention of certain manufacturers of implements and also from beet sugar company fieldmen, and aggressive cooperation of the Agricultural Engineer is urgently needed to bring about a speedy realization of mechanical harvest under a wide range of soil conditions.

The mechanical loading of topped beets from windrows has been successfully accomplished in many areas where cloddy soil conditions are not a handicap to this operation. Because of the fact that the mechanical loader incorporates clods with the beets in loading into trucks, the practice in certain areas has been to use cross-conveyors into which the topped beets are thrown by hand, and loaded directly into trucks. Regardless of the system used, further improvement in loader design is needed until such time as topping and loading can be made into truck direct.

Recital of jobs requiring attention of a qualified specialist would not be complete without reference to seedbed preparation, leveling devices, crust breakers, sleds for ridge planting, and similar equipment needed in preparing the soil for efficient mechanization work.

THE AGRONOMIST

In the production of stands of sugar beet plants, proper depth and rate of planting and the production of a full stand of seedlings regularly spaced are fundamental to the mechanization program. The question of proper space relationships between plants for production of largest yield, is still not well understood despite considerable literature on the subject. The space allotment found best in one area may be unwarranted in another area, where differences in soil moisture, soil type, and fertility of soil obtain. The question of the effect of soil mulch resulting from cultivating beets versus similar space patterns of beets uncultivated remains unanswered. The question of the effect of varietal performance as affected by space relationships between plants will necessarily vary as new varieties are developed. Such has been found to be the case in some of the varieties tested thus far under varying levels of fertility (8).

With rapid changes in the field of commercial fertilizer manufacture, development of synthetic materials, an unprecedented production of nitrogen fertilizers, and production of high plant food analysis goods, comes the need for specific handling of these fertilizers for larger sugar-per-acre yields. Shall some of this fertilizer be plowed under? What fertilizer placement is most effective? Are side dressings profitable, and at what time? Aside from the value of fertilization of the crop to the grower for increased yields, the industry has a right to demand that the beet so produced has good storing qualities in the storage pile until processed. Recent advances made in fertilization of muck soils (5) may cause a change in attitude toward acceptance of such soils for sugar beet production in the future. Then, too, as soils become more mature, fertilizer requirements change, and in many cases use of minor plant-food elements may be the determining factor between success and failure of the crop.

Because of the large field there is to cover, probably no other trained investigator has more problems confronting him than the agronomist. The question of handling preceding crops so as to exert a beneficial effect upon the beet crop is of primary importance. When and how to plow, and the influence of this operation on soil microflora; green manure, kinds and usage for both compliance and actual benefit to soil, and their effect upon quality of the beet crop; all of these operations are vital to successful beet agriculture.

Where beets are grown under irrigation, the problem of extending the length of the irrigating season to within a few days prior to harvest is posed in order to leave the soil in excellent condition for successful operation of the mechanical beet harvester and loader. This presents an opportunity for the agronomist to determine the latest safe date for application of irrigation water with respect to its effect upon the quality of the beet crop.

THE GENETICIST AND PLANT BREEDER

There can be no doubt of the contribution made by the geneticist and plant breeder to the welfare of the sugar beet industry. The winning of the West for sugar beets from the ravages of the curly-top

virus disease is well known to any grower in the Intermountain and Pacific Coast areas. Similar strides, though somewhat less spectacular, are being made in sugar beet-improvement in the areas where *Cercospora beticola* leaf spot is commonly prevalent. In American Crystal Sugar Company territories where leaf spot was a factor in 1943, the resistant variety American No. 1 excelled in percentage sucrose over susceptible varieties in every one of 20 replicated field tests, giving an average increase of 1.45% sucrose, or a total improvement of 10.6% for this important characteristic. One need but refer to the literature on this subject for other impressive testimony on this point.

The industry definitely believes in the full mechanization of beet culture and has confidence in the ability of the geneticist and plant breeder eventually to produce single-germ seed of superior varieties. In this development program, varieties of high vigor, high resistance to diseases and to bolting, and of a broad genetic base to insure high yield, will no doubt be forthcoming. Tetraploidy may or may not give the answer to increased yields but in any event deserves further study. Hybrids with other Beta species may uncover desirable genes. However, from the point of view of mechanization, certain morphological characters such as uniformity of foliage, height of crown, and size and shape of root would be most helpful to more satisfactory performance of mechanical equipment.

Anyone at all acquainted with the problem of beet breeding is at once impressed with the need for fundamental research in inheritance of disease resistance, self-sterility and self-fertility factors, sources of new genes, and the need of a more efficient breeding methodology. While progress in sugar beet breeding has been noteworthy, the general improvement in tonnage yields of adapted varieties has not as yet paralleled the success experienced in the synthesis of hybrid corn.

In the development of superior germ plasm, there is critical need for safeguarding it in subsequent increases of the seed. There appears to be some evidence that the environment has an influence on behavior of certain varieties of beets when the seed increase is made in areas which do not produce full bolting. Whether this is due to the photoperiod in stimulating a certain portion of the beet population to bolt while the other remains vegetative (and thus upsets the genetic composition of the variety), or whether it is largely a photothermal relationship is unknown. However, the fact that too often a rapid bolting tendency is observed in some of the commercial beets planted at an early date on very fertile soil would lead one to suspect the area where the seed increase was made as being responsible for this condition. It is evident that some carefully conducted work along the lines indicated is necessary.

THE PLANT PATHOLOGIST

From standpoint of seedling disease effects upon stand, the manner in which such treatment of segmented seed can best be accomplished, rate of deterioration of treated seed in storage, and possible prevention

or reduction of the same, the effect of soil sanitization through proper crop rotation procedures to insure good stands—these are some of the problems clamoring for the attention of the pathologist. There are certain indications that treatment of seed remains effective and that treated seed may be stored for longer periods of time with safety, provided the fungicide is combined with some other diluent which will not decrease the active properties of the mercury or other protective compound.

The appearance of certain diseases, such as *Fusarium sp.*, *Rhizoctonia solani*, *Sclerotium rolfsii*, *Aphanomyces cochlioides*, and others, often in epidemic proportions, leads one to surmise that the field of the plant pathologist is still a wide-open one in working out methods whereby appreciable losses from these and other diseases may either be averted or measurably reduced. Effective work by the pathologist has already been done in this field in certain areas of this country, but apparently much more remains to be done elsewhere in working out control measures.

Then, too, there are certain malnutritional diseases as a result of mineral plant food deficiencies, and concerning which the pathologist could do great service in recognizing deficiency symptoms and in prescribing necessary treatment for relief. He could also be helpful in developing technics to insure better keeping quality of beets in the storage pile and the consequent reduction in sugar loss through use of certain hormones and fungus-arresting materials. There is great need for this type of research for which this specialist is particularly well prepared through previous training.

CONCLUSIONS

Certain phases of the mechanization program of sugar beet culture undertaken in 1943 have been successfully demonstrated and warrant the belief that complete mechanization of the industry will be accomplished at an early date. With the realization of the program, it would more nearly approach the ideal situation of year around supply of farm labor handling the entire cultural and harvesting operations without the necessity of hiring additional seasonal labor.

The beet sugar industry is confident that mechanization of sugar beet culture is a demonstrated fact and that the tempo with which it is put into wholesale reality will largely be conditioned by the cooperative assistance of all concerned. The implement manufacturers also have faith in the program and are venturing large sums of money into the construction of machinery which is capable of fully meeting the critical factors involving the use of equipment in the revolution in sugar beet agriculture.

LITERATURE CITED

1. Bainer, Roy. New developments in sugar beet production. Jour. Amer. Soc. Agr. Eng., 24:225–258. 1943.
2. Carsner, E. Curly-top resistance in sugar beets and tests of the resistant variety U. S. No. 1. U.S.D.A. Tech. Bul. 360. 1933.
3. Coons, G. H. Improvement of the sugar beet. S.U.D.A. Yearbook, 1936:652–656. 1936.

4. ELCOCK, H. A., and OVERPECK, J. C. Methods of producing sugar beet seed in southern New Mexico. N. M. Agr. Exp. Sta. Bul. 207. 1933.
5. HARMER, M. PAUL. Salt with potash for some crops. Better Crops with Plant Food, June–July, 1943.
6. MAYNARD, JACK. What 106 tests on beet by-products mean to you. Through the Leaves, Sept. –Oct., 1943.
7. MERVINE, E. M., and BARMINGTON, R. D. Mechanical thinning of sugar beets. Colo. Agr. Exp. Sta. Bul. 476. 1943.
8. SKUDERNA, A. W., and DOXTATOR, C. W. Effects of varying levels of soil fertility upon sugar and tonnage varieties of sugar beets. Proc. Amer. Soc. Sugar Beet Tech., 1942:— —. 1944.
9. ————, *et al*. Evaluation of sugar beet types in certain beet-growing districts in the United States. U.S.D.A. Circ. 476. 1938.
10. ————, and SHEETS, E. W. Important sugar beet by-products and their utilization. U.S.D.A. Farmers' Bul. 1718. 1934.

THE EFFECT OF NITROGEN FERTILIZATION ON THE GROSS MORPHOLOGY OF TIMOTHY, *PHLEUM PRATENSE* L.[1]

J. C. Anderson[2]

LARGE amounts of cheap nitrogen fertilizer will likely be available soon for widespread agricultural use. This situation prompted some investigation into the possible benefits and hazards which might arise in using nitrogen on timothy sod. Timothy was chosen because it is the most important grass hay in the northeastern states. Since the leaves are the more valuable part of the hay crop because of their high feeding value, it is important to know how and when to apply this nitrogen to obtain high yields of leafy hay.

At stated intervals during the life cycle of timothy, Trowbridge, Haigh, and Moulton (4)[3] harvested the crop, which had been grown under uniform fertilizer treatment, and reported the dry weight per acre of each of the plant parts. Brown and Munsell (2) and Sprague and Hawkins (3) applied nitrogen carriers to timothy sod in April and again in June. The determination of dry matter, without attempt to separate the plant organs, indicated a marked stimulation from the April applications only.

The purpose of the research herein reported was to determine the gross morphological response of timothy to April and June applications of nitrogen fertilizer.

METHODS

The field of timothy used in this experiment was planted in August, 1939. A 4–12–6 fertilizer had been uniformly applied to the field at the rate of 400 pounds per acre in the spring to produce a crop of oats. In April, 1940, the field was divided into 40 plots, and nine treatments, as designated in Table 1, were systematically replicated four times. The source of soluble nitrogen was sodium nitrate, since it is one of the most readily obtainable nitrogen carriers in ordinary times and because experiments (1) with several nitrogen carriers indicated that the largest percentage of nitrogen in the form of crude protein was recovered from $NaNO_3$ by the timothy plant. Manure was used to test a source of nitrogen available on farms where timothy is raised for feeding livestock. It was applied at the rate of 10 tons per acre.

Each plot was 78 × 8 feet and was divided equally into three sub-plots measuring 26×8 feet. The sub-plots were harvested for hay as follows: First sub-plot, June 10, early bloom (5% of heads shedding pollen); second sub-plot, June 20, full bloom (90% of heads shedding pollen); third sub-plot, June 30, late bloom (10% of heads still shedding pollen).

Representative samples were obtained by mixing eight handfuls of timothy taken from representative places on each replicated sub-plot. The plants were segregated into corms, stems, green leaves with sheaths included, heads, and dead leaves. These plant parts were oven-dried to constant weight. The yield of each organ was calculated on the basis of its dry weight per acre and its percentage of the total dry weight was also determined.

---

[1]Journal Series paper of the New Jersey Agricultural Experiment Station, Rutgers University, Department of Agronomy, New Brunswick, N. J. Received for publication November 18, 1943.

[2]Research Assistant in Agronomy. Acknowledgment is given Dr. G. H. Ahlgren for his assistance in the preparation of this paper.

[3]Figures in parenthesis refer to "Literature Cited", p. 589.

The analysis of variance method was used to test the data obtained for the significance of the effect of the treatments. It is recognized that the use of analysis of variance on data from systematically replicated plots is subject to certain limitations, but the results have been used only as an aid in the interpretation of the experimental data obtained.

RESULTS

Nitrogen in the form of sodium nitrate applied to timothy sod in April stimulated the production of total dry matter (designated "whole plant" in Table 1). This increased yield was found at the early, full, and late bloom stages of growth. Plots which received manure yielded significantly more dry matter than the non-treated ones at the early bloom stage but not at the full or the late bloom stage. The 30- and the 60-pound applications of soluble nitrogen in April resulted in approximately the same total yield, and applying nitrogen at the early bloom stage in June failed to stimulate yield further regardless of the April treatment or the amount applied.

The mean squares in Table 2 show that the April fertilizer treatments did not produce significant differences in the yields of corms, harvested at the early bloom stage. Yields of corms at full and late bloom, however, were greatly affected by the April treatments. The June treatments had no appreciable or consistent effect. The means for all treatments at the various growth stages show that the corms reached a peak in yield of dry matter at full bloom. In the 10-day period following, the corms decreased in yield on an average of 127 pounds per acre.

Stem yields at all three stages of bloom were markedly affected by treatment differences, except when manure was applied, in which case the yield was comparable ot that of plots receiving no treatment.

The 30-pound applications of nitrogen in April resulted in greater dry weight of stems than the no-treatment, and the 60-pound applications increased stem yields still further. This difference in effect on yield of stems was true at all three stages of maturity. The use of nitrogen at early bloom generally was without effect on the yield of dry matter in stems. Appreciably less dry weight of timothy stems was produced on plots which had received 60 pounds of nitrogen in June in addition to 60 pounds in April than was produced on plots which had received only the April treatment. During the period between early and late bloom there was an average increase of 1,721 pounds per acre in the dry weight of stems from all plots.

The effects of the treatments on the dry weights of green leaves were highly significant for the three stages of maturity. The control plots and those manured in April yielded less green-leaf dry matter at early and full bloom than did those plots treated with either 30 or 60 pounds of nitrogen in early spring. By the late bloom stage the effect of April applications of nitrogen on the yield of green leaves had largely disappeared. The larger yields of green leaves resulting from applications of nitrogen at early bloom were evident by the time of the full bloom stage. By late bloom these differences in yield of green leaves had increased but were significant only for those plots which had received the 30-pound application at early bloom. Plot 10, to which 60 pounds of nitrogen had been applied at early bloom, showed

TABLE 1.—*Effect of April and June applications of nitrogen to timothy on the yields of dry matter and percentages per acre of whole plant, corms, stems, green leaves, heads, and dead leaves, at three cutting dates.**

Plot No.	Nitrogen applied†		Whole plant			Corms			Stems			Green leaves			Dead leaves			Heads		
	Apr. 1	June 10	June 10	June 20	June 30	June 10	June 20	June 30	June 10	June 20	June 30	June 10	June 20	June 30	June 10	June 20	June 30	June 10	June 20	June 30
1	—	—	2,635 (100.0)	3,544 (100.0)	4,011 (100.0)	618 (23.6)	719 (20.3)	587 (14.7)	667 (25.1)	1,454 (40.9)	2,315 (57.3)	1,171 (44.5)	1,027 (29.1)	505 (12.7)	81 (3.1)	157 (4.4)	357 (8.9)	99 (3.7)	188 (5.3)	247 (6.4)
2	30	—	4,229 (100.0)	5,243 (100.0)	5,478 (100.0)	855 (20.2)	1,055 (19.9)	803 (14.7)	1,279 (30.2)	2,180 (41.7)	3,119 (56.9)	1,838 (43.5)	1,391 (26.7)	509 (9.3)	142 (3.3)	395 (7.4)	721 (31.2)	116 (2.8)	223 (4.3)	327 (5.9)
3	30	30	4,375 (100.0)	5,131 (100.0)	5,243 (100.0)	848 (19.4)	998 (19.5)	672 (12.8)	1,424 (32.5)	2,085 (40.7)	3,085 (58.8)	1,730 (39.6)	1,506 (29.4)	652 (12.4)	149 (3.4)	324 (6.2)	564 (10.8)	224 (5.1)	218 (4.2)	271 (5.2)
4	M	—	3,447 (100.0)	3,531 (100.0)	3,629 (100.0)	726 (21.6)	697 (19.8)	533 (14.6)	986 (28.5)	1,470 (41.5)	2,126 (58.6)	1,459 (42.4)	1,018 (29.1)	421 (11.6)	99 (2.9)	167 (4.6)	346 (9.6)	157 (4.6)	179 (5.0)	203 (5.6)
5	M	30	3,164 (100.0)	3,958 (100.0)	4,530 (100.0)	722 (22.6)	725 (18.4)	637 (14.0)	857 (27.3)	1,660 (41.7)	2,669 (58.7)	1,342 (42.2)	1,183 (30.2)	611 (13.7)	100 (3.1)	139 (3.5)	385 (8.4)	144 (4.8)	251 (6.2)	229 (5.2)
6	—	—	2,662 (100.0)	3,559 (100.0)	4,106 (100.0)	624 (23.2)	619 (17.4)	612 (14.8)	663 (25.0)	1,509 (42.3)	2,367 (57.7)	1,193 (44.9)	1,011 (28.5)	472 (11.4)	66 (2.4)	166 (4.7)	406 (10.0)	116 (4.5)	255 (7.1)	248 (6.1)
7	60	—	4,792 (100.0)	5,497 (100.0)	6,177 (100.0)	798 (16.7)	826 (15.1)	819 (13.3)	1,593 (33.2)	2,527 (45.8)	3,696 (59.7)	1,861 (38.8)	1,350 (24.7)	524 (8.4)	337 (6.9)	467 (8.4)	806 (13.1)	208 (6.0)	327 (6.0)	333 (5.5)
8	60	60	4,454 (100.0)	5,270 (100.0)	5,490 (100.0)	680 (15.4)	872 (16.5)	781 (14.2)	1,581 (35.5)	2,151 (40.9)	3,170 (57.6)	1,677 (37.6)	1,539 (29.2)	479 (8.8)	292 (6.4)	402 (7.6)	778 (14.1)	224 (5.1)	307 (5.8)	283 (5.3)
9	—	30	3,026 (100.0)	4,035 (100.0)	4,888 (100.0)	657 (22.2)	712 (17.8)	744 (15.2)	823 (27.0)	1,712 (42.1)	2,808 (57.4)	1,339 (44.2)	1,147 (28.9)	672 (13.8)	73 (2.4)	195 (4.7)	399 (8.1)	135 (4.2)	268 (6.5)	266 (5.5)
10	30	60	4,033 (100.0)	5,200 (100.0)	5,317 (100.0)	765 (19.1)	978 (19.3)	737 (13.9)	1,347 (33.1)	2,066 (38.7)	3,074 (57.8)	1,606 (40.0)	1,500 (29.3)	631 (11.9)	138 (3.4)	325 (6.3)	571 (10.7)	178 (4.4)	332 (6.4)	304 (5.7)
Average........			3,682 (100.0)	4,497 (100.0)	4,877 (100.0)	731 (20.4)	820 (18.4)	693 (14.2)	1,122 (29.7)	1,881 (41.6)	2,843 (58.1)	1,522 (41.8)	1,267 (28.5)	548 (11.4)	148 (3.7)	274 (5.8)	533 (10.7)	160 (4.4)	255 (5.7)	271 (5.6)
Sig. diff. at 5% level			496 (——)	667 (——)	903 (——)	—— (3.7)	176 (——)	144 (1.3)	224 (3.6)	302 (——)	556 (——)	228 (4.5)	192 (2.7)	126 (1.6)	102 (——)	104 (1.7)	51 (2.1)	89 (——)	105 (——)	—— (——)

*Results given in pounds per acre, with percentages shown in parenthesis.

†The treatments consisted of 30- and 60-pound per acre applications of nitrogen in the form of $NaNO_3$ on the dates indicated. The letter M indicates manure which was applied at the rate of 10 tons per acre. The check plots had only the basic applications of 4–12–6 fertilizer and limestone applied to the whole plot area.

TABLE 2.—*Mean squares from analysis of variance of data presented in Table 1.*

Variation due to	D.F.	Yield of dry matter																	
		Whole plant			Corms			Stems			Green leaves			Dead leaves			Heads		
		June 10	June 20	June 30	June 10	June 20	June 30	June 10	June 20	June 30	June 10	June 20	June 30	June 10	June 20	June 30	June 10	June 20	June 30
Treatment......	9	** 2,497,882 **	** 2,789,788 **	** 2,567,455	** 29,933 *	** 89,514 **	** 38,689 **	** 531,252 **	** 543,519 **	** 921,487	** 262,131 **	** 184,083 *	** 30,089 *	** 34,799	** 59,801 **	** 158,551 **	* 8,584	* 11,822 **	6,778 *
Replication......	3	1,156,734	2,256,962	895,764	31,582	78,086	41,604	125,534	587,212	392,509	202,727	46,839	14,253	10,786	49,457	4,696	7,049	74,959	9,510
Error...........	27	117,026	211,418	388,144	13,467	14,764	9,849	23,864	44,150	146,829	24,662	17,527	7,511	4,953	5,115	1,249	3,770	5,242	3,905
Total...........	39																		

Variation due to	D.F.	Percentage yields														
		Corms			Stems			Green leaves			Dead leaves			Heads		
		June 10	June 20	June 30	June 10	June 20	June 30	June 10	June 20	June 30	June 10	June 20	June 30	June 10	June 20	June 30
Treatment......	9	** 306.6	114.9 **	* 22.2 **	** 551.9	125.9 *	29.0	* 274.7	* 104.0 **	** 151.1	50.4	** 106.8 **	** 180.5	19.1	36.1	6.4 **
Replications.....	3	19.2	203.9	31.2	23.4	231.5	42.7	65.6	323.7	14.1	25.9	80.6	7.0	57.1	24.5	59.6
Error...........	27	65.3	55.9	7.6	61.3	102.6	30.8	98.2	33.7	12.4	36.5	14.2	20.6	30.3	18.3	11.8
Total...........	39															

*Exceeds the 5% point.
**Execeds the 1% point.

no increase in yield of green-leaf dry matter when compared with its control, plot 3, which had received only 30 pounds of nitrogen at that time. The yield of green leaves for all treatments decreased, on the average, about 300 pounds per acre during the period from early to full bloom and a total of almost 1,000 pounds from early to late bloom. Soluble nitrogen applied at early bloom tended to reduce the loss of green leaves as the timothy plant approached maturity.

The yields of dead leaves at early, full, and late bloom were markedly affected by the various treatments. The highest yields of dead leaves at the early bloom harvest were produced on the plots which had received 60 pounds of nitrogen in April. The other April treatments ranked, in yield of dead leaves at early and full bloom, from low to high, as follows: No treatment, manure, and 30 pounds of nitrogen per acre. Nitrogen applications at the early bloom stage had no appreciable effect on the yields of dead leaves, except for plot 3, on which the yield at the late bloom harvest was significantly lower than for its check plot, 2.

The yields of heads at the early and full bloom stages of growth, though affected by fertilizer treatment, make up a negligible portion of the whole-plant yields and will not be discussed.

Table 2 shows that at early bloom, the treatments had a marked effect on the percentage of corms, stems, and green leaves. The green-leaf and dead-leaf percentage yields at full and late bloom were significantly affected by treatment.

At early bloom the percentage yields of corms and green leaves, as shown in Table 1, tended to be depressed as a result of heavy applications of soluble nitrogen in April. At the same time there was a rise in the percentage of stems. The average percentage of green leaves decreased from 41.8 to 28.5 between early and full bloom and then dropped to 11.4 in the next 10-day period. At full and at late bloom the yield of green leaves showed a consistent though not always significant increase in response to nitrogen applied at early bloom. The percentage yields of dead leaves generally decreased in response to this treatment.

DISCUSSION

Soluble nitrogen applied to timothy sod at the rate of 30 pounds of nitrogen per acre can be beneficial in more ways than merely increasing total dry weight. Nitrogen applied at this rate at early bloom increased the dry weight of green leaves harvested in timothy hay by 100 to 300 pounds per acre. Applications of 60 pounds of soluble nitrogen per acre in April or in both April and June did not stimulate a greater yield of dry matter than did similar 30-pound applications. Applications of 30 pounds of soluble nitrogen at the early bloom stage resulted in as large yields as did 60-pound applications. The net increase in yield of green leaves per pound of nitrogen applied at early bloom was twice as great for the 30-pound as for the 60-pound applications of that element. Yields of whole plant in response to the two rates were not significantly different. With the 60-pound nitrogen application, however, the proportion of green leaves to total

plant was, therefore, decreased and that of the dead leaves increased because of lodging.

The use of a cyclone seeder to apply the nitrate of soda resulted in little trampling down of the hay. In the course of a few days any plants that were originally lodged by trampling had grown partly erect and the resultant loss was negligible.

SUMMARY

1. A study was made to determine the effect on timothy of April and June applications of soluble nitrogen supplied at rates of 30 and 60 pounds per acre.

2. Nitrogen applied in April consistently promoted yields of dry matter greater than those from the non-treated plots. Plots that received 60 pounds of nitrogen per acre produced a lower quality hay due to lodging and the subsequent loss of green leaves. Lodging did not occur on the no-treatment plots or on those plots receiving manure at the rate of 10 tons or nitrogen at the rate of 30 pounds per acre. The gross morphological composition of timothy grown on plots treated in April with 30 pounds of nitrogen per acre did not differ greatly from that of timothy grown on untreated plots.

3. A sharp drop in the percentage yield as well as the total yield of green leaves occurred after full bloom in all treatments studied.

4. The yields of green leaves from plots receiving 30- and 60-pound applications of nitrogen in both April and June were about equal, and they were significantly higher than the yields from the non-treated plots. The net increase in yield of green leaves per pound of nitrogen applied at early bloom was twice as great for the 30-pound rate of application as for the 60-pound application.

LITERATURE CITED

1. ANDERSON, J. C. A study of carbohydrate-nitrogen relations in timothy plant tops. Rutgers University Thesis. 1940.
2. BROWN, B. A., and MUNSELL, R. I. Grasses fertilized with nitrogen compared with legumes for hay and pasture. Jour. Amer. Soc. Agron., 35:811–816. 1943.
3. SPRAGUE, H. B., and HAWKINS, A. Increasing the protein content of timothy without sacrificing yield, by delayed applications of nitrogenous fertilizers. N. J. Agr. Exp. Sta. Bul. 644. 1938.
4. TROWBRIDGE, P. F., HAIGH, L. D., and MOULTON, C. R. Studies of the timothy plant. Part II. Mo. Agr. Exp. Sta. Res. Bul. 20. 1915.

THE EFFECTS OF FERTILIZATION, SPECIES COMPETITION, AND CUTTING TREATMENTS ON THE BEHAVIOR OF DALLIS GRASS, *PASPALUM DILATATUM* POIR., AND CARPET GRASS, *AXONOPUS AFFINIS* CHASE[1]

R. L. LOVVORN[2]

APPROXIMATELY 85% of the total cultivated crop acreage in North Carolina was fertilized in 1942 (7).[3] There are no available estimates of the plowable pasture acreage that was fertilized, but it is known that little fertilizer is applied to this crop. This is partially explained by the fact that North Carolina farmers have not been primarily interested in grassland farming.

North Carolina can be divided into two climatic zones with reference to the adaptation of pasture species. The western portion of the state is suitable to the species that are grown in the more northern regions of the United States. This paper will not include the adaptation studies of these species, since their response to fertilization and management is similar to observations made by other workers (5,6).

The eastern portion of the state falls south of the 60° isotherm; within this area both Dallis grass and carpet grass are grown. Bledsoe and Sell (2) have reported that southern pasture species, namely, carpet, Dallis, and Bermuda grass, respond slightly to applications of calcium, moderately to phosphorus, and greatly to nitrogen. The adaptation of southern species has also been investigated by Mayton (3), Blaser and Stokes (1), and Ritchey and Henley (4).

Most of the investigations with these grasses have included the effects of fertilization upon the yields of mixtures of grasses and legumes. The practice of seeding a mixture of Dallis grass and carpet grass often results in virtually pure stands of the latter within a few years. Information on the relative yielding abilities of the two grasses, their behavior when grown in association with legumes, and their response to fertilization and management practices would provide information basic to the management of such permanent pastures.

METHODS

FIELD STUDIES

The field phase of the study was conducted on a Norfolk fine sandy loam soil of the upper Coastal Plain and a Lynchburg fine sandy loam soil of the lower Coastal Plain. The Norfolk was well drained and had been fertilized in previous years. The Lynchburg was poorly drained. The base exchange capacity and percentage base saturation are given in Table 1. On both fields the design was a split plot in which the fertilizer treatments were the whole plots and the seeding mixtures were the subplots.

---

[1]Contribution from the Department of Agronomy, North Carolina Agricultural Experiment Station, Raleigh, N. C., and the Division of Forage Crops and Diseases, Bureau of Plant Industry, Soils, and Agricultural Engineering, Agricultural Research Administration, U. S. Dept. of Agriculture. Published with the approval of the Director as paper No. 174 of the Journal series. Received for publication January 6, 1944.

[2]Associate in Agronomy (Forage Crops), North Carolina Agricultural Experiment Station.

[3]Figures in parenthesis refer to "Literature Cited", p. 600.

TABLE 1.—*The exchange capacity, exchangeable bases, and percentage base saturation of the unfertilized Norfolk fine sandy loam and Lynchburg fine sandy loam.**

Soil	Base exchange capacity	Exchangeable bases	Percentage base saturation
Norfolk fine sandy loam.......	2.43	0.73	30.0
Lynchburg fine sandy loam....	13.95	2.35	16.8

*Samples taken to a depth of 6 inches at end of period in which data are presented in this paper.

Fertilizer treatments on the Norfolk soil consisted of O, P, PK, NPK, PKCa, and NPKCa, respectively.[4] Seedings made in March, 1937, consisted of (A) 20 pounds Dallis grass, *Paspalum dilatatum* Poir.; and (B) 20 pounds carpet grass, *Axonopus affinis* Chase.

The adaptation study on the Lynchburg soil was begun in March, 1940. The fertilizer treatments consisted of O, NPK, NPCa, NKCa, PKCa, and NPKCa, respectively.[5] Within each fertilizer plot the subplots were seeded to the following species: (A) 20 pounds of Dallis grass and 10 pounds of Kobe lespedeza, *Lespedeza striata* (Thumb.) H. and A.; (B) 20 pounds of Dallis grass and 5 pounds of Kent wild white clover, *Trifolium repens* L.; (C) 20 pounds of Dallis grass and 10 pounds of low hop clover, *Trifolium procumbens* L.; and (D) 20 pounds of Dallis grass.

A management study was also initiated on the Lynchburg soil. A series of plots fertilized with a complete fertilizer plus limestone and seeded to a mixture of Dallis grass, white clover, and low hop clover were harvested according to the following schedule:

A. Harvested every 2 weeks
B. Harvested every 4 weeks but omitting first two cuttings (April and May)
C. Harvested every 4 weeks but omitting two midsummer cuttings (June and July)
D. Harvested every 4 weeks but omitting last two cuttings (Aug. and Sept.)

No carpet grass was seeded to either of the experiments located on the Lynchburg soil. These experiments were seeded, however, on land that had previously been in a carpet grass pasture but was planted to soybeans in 1939. Although the soybeans were cultivated and kept free of carpet grass, a considerable amount of this grass volunteered in all plots.

Harvests were made approximately once each month throughout the growing period unless otherwise specified. The vegetation was cut to a height of 1 inch at each harvest. Botanical analyses were made during the spring and fall of each year by means of the inclined point quadrat (8). Readings were made at 10 randomized locations on each 5×30 foot plots, and the data have been reported as the number of hits per plot.

GREENHOUSE STUDIES

Dallis grass and carpet grass were grown in pure stands at two fertility levels in the greenhouse during the winters of 1941–42 and 1942–43. A high soil fertility level was established by adding nitrate of soda, superphosphate, muriate of potash, and limestone at the rates of 300, 800, 200, and 2,000 pounds per acre, respectively. No fertilizer was added to the soil maintained at the low-fertility level. The soil, a Norfolk fine sandy loam, was obtained from an area adjacent to the field in which one of the studies previously described was conducted. The cutting treatments consisted of defoliating the plants to a height of 1 inch at 10-, 20-, and 30-day intervals during 1941–42. During 1942–43 a fourth series was added

[4]N = 300 pounds nitrate of soda annually, 200 pounds in the spring and 100 pounds in the fall; P = 800 pounds superphosphate every 4 years; K = 200 pounds muriate of potash every 4 years; Ca = 2 tons dolomitic limestone applied at beginning of experiment.

[5]N = 200 pounds nitrate of soda annually, 100 pounds in the spring and 100 pounds in the fall; P, K, and Ca rates of application were same as in experiment on Norfolk soil.

in which the grasses were not harvested until the experiment was terminated or 60 days after the first defoliations were made. Since the grasses behaved similarly in both years, only the 1942–43 data will be reviewed.

RESULTS

FIELD STUDIES

The yields in pounds of air-dry matter per acre from the study on the Norfolk fine sandy loam soil are shown in Table 2. These data indicate that carpet grass was inferior to Dallis grass regardless of the fertilizer treatment and that carpet grass did not respond to the mineral fertilizer treatment. The slight response of Dallis grass to superphosphate was not statistically significant, but the increase resulting from the superphosphate plus potash treatment was significant. Both grasses responded greatly to applications of nitrogen.

TABLE 2.—*Yields of dry matter in pounds per acre of Dallis grass and carpet grass with various fertilizer treatments on Norfolk fine sandy loam, average annual yield 1938–42.*

Seedings	Fertilizer treatment*					
	None	P	PK	NPK	PKCa	NPKCa
Dallis	917	1,005	1,158	2,158	1,032	1,911
Carpet	731	740	725	1,695	686	1,586

*The least significant difference between seedings within any fertilizer treatments at 5% level, 179; at 1% level, 238.

Since Dallis grass proved to be superior to carpet grass on the Norfolk experiment, it was used as the basic grass in the establishment of the experiment on the Lynchburg fine sandy loam soil. The three years' results are given in Table 3 and Fig. 1. The inadequacy of Dallis grass alone is clearly indicated. The nitrate of soda was the only fertilizing material that stimulated the grass. Even though Dallis grass was the only grass seeded, the actual sward consisted of a mixture of Dallis grass and carpet grass. Carpet grass volunteered on all plots. It is not surprising, therefore, that the grass yield was not affected by mineral fertilizers since pure stands of carpet grass did not respond to this treatment in the previous experiment. The botanical composition of the sward was affected, but these data will be discussed later.

Superphosphate, potash, and limestone were necessary for Kent wild white clover. The yields from the Dallis grass-Kent wild clover were larger following the complete fertilizer treatment than following the mineral fertilizer treatment in 1941 and 1942. The difference between the two treatments were not large, however, during either of the three years.

The stand of low hop clover was poor in 1941, and the yield was significantly larger following the nitrogen fertilization. The yields following the mineral fertilizer and the complete fertilizer were approximately the same in 1942 and 1943. The lespedeza made fair

TABLE 3.—*Yields of dry matter in pounds per acre of grasses with and without legumes and with various fertilizer treatments on Lynchburg fine sandy loam.*

Year	Fertilizer treatment*						
	None	NPK	NPCa	NKCa	PKCa	NPKCa	Average
			Dallis-Lespedeza				
1941	2,952	3,007	3,320	3,289	3,364	3,717	3,275
1942	1,418	2,207	1,979	2,297	1,694	2,086	1,947
1943	1,646	2,681	2,243	2,407	1,486	2,573	2,173
Average	2,005	2,632	2,514	2,664	2,181	2,792	2,465
			Dallis-Kent Wild White Clover				
1941	1,911	2,339	3,048	2,749	3,435	3,791	2,879
1942	957	1,598	1,884	1,868	1,852	2,220	1,730
1943	1,317	2,415	2,359	2,387	3,175	2,911	2,436
Average	1,413	2,117	2,430	2,355	2,821	2,974	2,348
			Dallis-Low Hop Clover				
1941	1,652	2,260	2,433	2,882	1,732	2,330	2,215
1942	1,138	2,477	3,055	3,158	2,970	3,110	2,651
1943	1,444	2,858	30,17	2,963	3,008	2,679	2,661
Average	1,411	2,532	2,835	3,001	2,570	2,706	2,509
			Dallis				
1941	1,649	2,110	2,315	1,877	1,536	2,035	1,920
1942	1,000	1,491	1,498	1,227	804	1,332	1,225
1943	1,269	2,165	2,121	1,532	918	1,795	1,633
Average	1,306	1,922	1,978	1,545	1,086	1,712	1,593
Av. of all seedings	1,534	2,301	2,439	2,386	2,164	2,548	——

*The least significant difference between seedings within any fertilizer treatment:

	1941	1942	1943
5% level	244	197	254
1% level	323	261	366

growth in 1940 and 1941, but during the last two years has been disappointing, regardless of treatment. The similarity between the curves in Fig. 1, showing the yields of Dallis grass and Dallis-lespedeza, is indicative of the poor growth of the lespedeza. No explanation is apparent as to the cause of the unsatisfactory growth of the lespedeza.

The monthly yields of the four types of swards under a low and high nitrogen system of soil fertilization are given in Fig. 2. Low hop clover was more beneficial in providing forage for early grazing when no nitrogen was applied. This clover made much more early growth than any of the species used. The spring yields of the mixtures of Kent wild White clover and lespedeza with Dallis grass were not increased by applications of nitrate of soda. All seeding combinations made much more growth in the fall following nitrate applications.

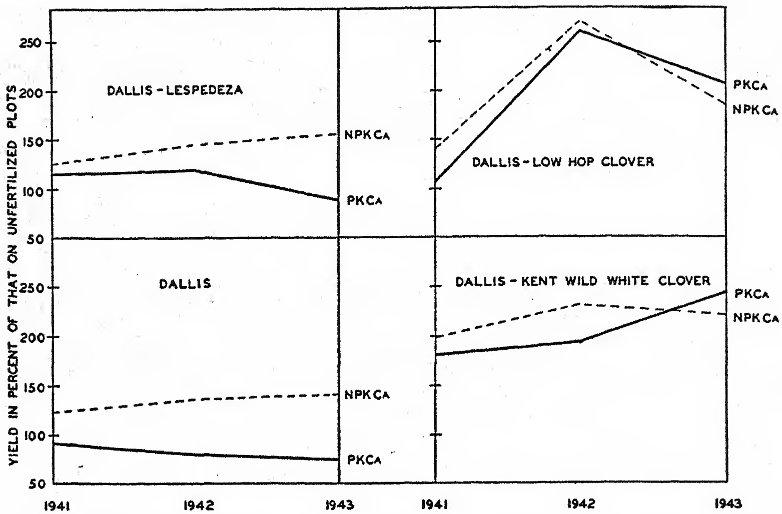


FIG. 1.—The yield of grasses with and without legumes and with different fertilizer treatments. Lynchburg fine sandy loam. Yield on unfertilized plot = 100.

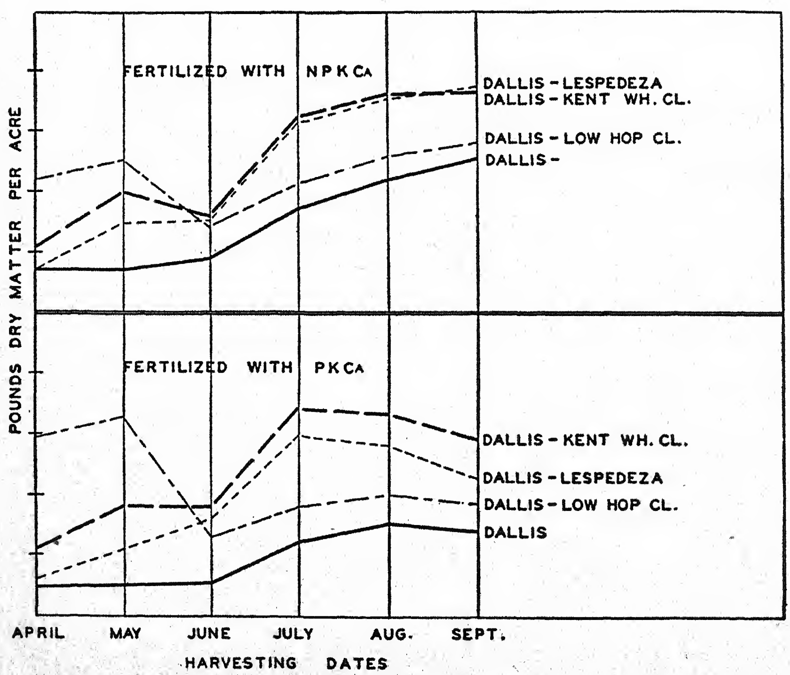


FIG. 2.—Monthly yields of Dallis grass with and without legumes and fertilized with and without nitrogen. Lynchburg fine sandy loam, 1941–43.

Plant population readings were made in the fall of 1940, following the seedings the previous spring and each spring and fall thereafter. The actual readings of carpet grass and Dallis grass growing together in the Dallis grass plots are given in Figs. 3 to 6. In every figure the total hits for each each of the two grasses were obtained from the same plot. The data are not included for the legume population.

The results of the spring and fall plant population analyses (Figs. 3 and 4) indicate that the absolute quantities of carpet grass have been increasing since 1940 and that the amount of Dallis grass has been decreasing during the same period. There is an inverse relationship between the behavior of the two grasses. That there is less carpet

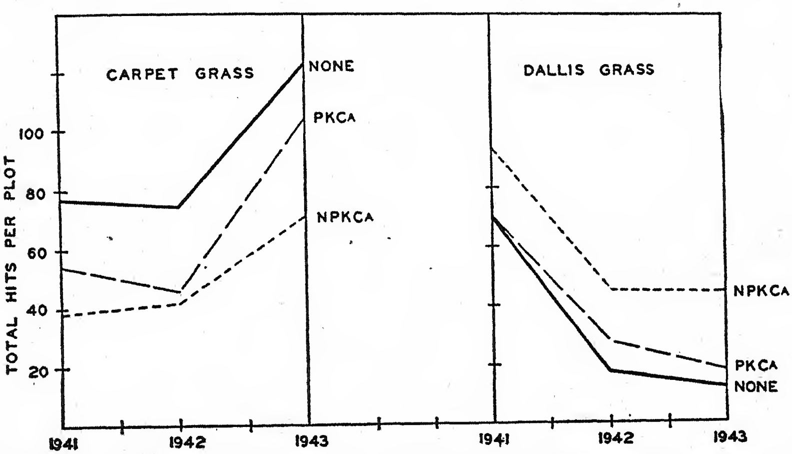


FIG. 3.—Total hits of carpet grass and Dallis grass with three fertilizer treatments. Lynchburg fine sandy loam, botanical analyses made in the spring.

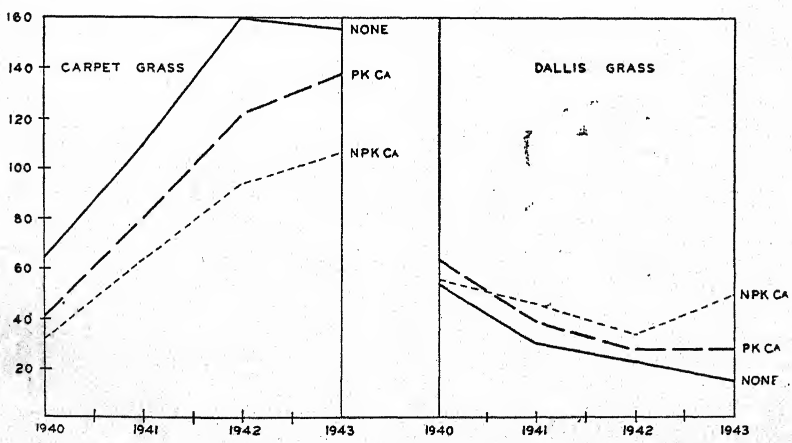


FIG. 4.—Total hits of carpet grass and Dallis grass with three fertilizer treatments. Lynchburg fine sandy loam, botanical analyses made in the fall.

grass with an increase in fertility is not interpreted as meaning that such fertilizers are detrimental to its growth but that Dallis grass is more responsive and increases at the expense of the less responsive grass.

That the presence of legumes in the sward will influence the ratio of carpet grass to Dallis grass is shown in Figs. 5 and 6. The total hits

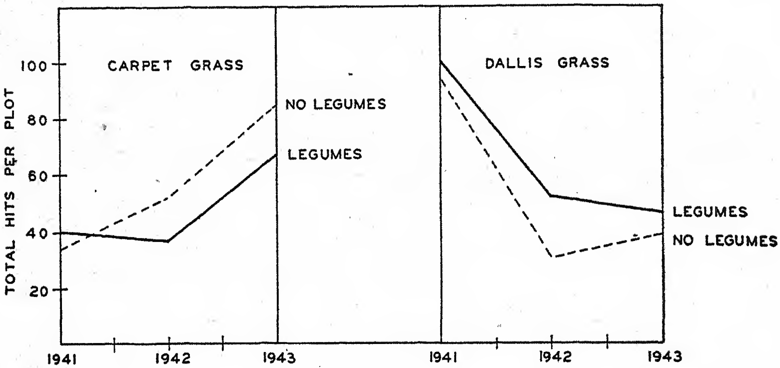


FIG. 5.—Total hits of carpet grass and Dallis grass when grown alone and with legumes. Lynchburg fine sandy loam, botanical analyses made in the spring.

of the grasses are shown when grown alone and in combination with legumes. The legume value is an average of the grasses when grown with lespedeza, white clover, and Kent wild white clover. These analyses were made on plots receiving a complete fertilizer plus limestone. The presence of a legume has reduced the rate at which carpet grass encroaches upon Dallis grass. The trend, however, is still toward a dominance of carpet grass regardless of the legumes present or the soil treatments used.

Harvesting every 2 weeks resulted in an annual yield of 2,813 pounds of air-dry matter per acre (Table 4). The largest total yields were obtained by omitting either the two spring harvests or two summer harvests. The unusually large yield following a period in which no harvests were made is due to the accumulated plant material

TABLE 4.—*The seasonal yield in pounds of dry matter per acre from different systems of management.*

Harvesting schedule	Yields of forage during			
	Spring	Summer	Fall	Total
Harvested every 2 weeks.............	507	997	1,309	2,813
Harvested every 4 weeks, but omitting first 2 cuttings....................	—	2,043	1,360	3,403
Harvested every 4 weeks, but omitting 2 midsummer cuttings.............	879	—	2,545	3,427
Harvested every 4 weeks, but omitting last 2 cuttings..................	715	1,062	—	1,777

that was not previously harvested. Since this accumulated material could not be carried forward into the following year, the system in which no harvests were made in the fall was at a disadvantage. This is illustrated in the low annual yield of 1,777 pounds following no harvesting in the fall.

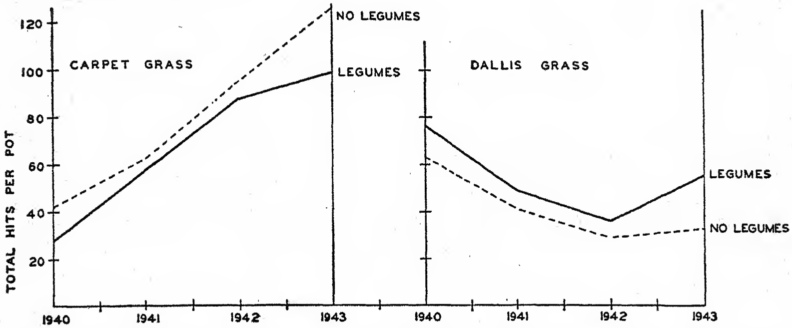


FIG. 6.—Total hits of carpet grass and Dallis grass when grown alone and with legumes. Lynchburg fine sandy loam, botanical analyses made in the fall.

It was observed that low hop clover was the dominant legume when no harvests were made in the spring. Omitting the two harvests in the fall was most favorable for lespedeza, whereas, harvesting every 2 weeks was most favorable for the white clover. The behavior of carpet grass and Dallis grass under these two systems of management is illustrated in Fig. 7. No botanical analyses were made in the spring on those plots that were not harvested that season. Likewise, no fall readings were made on those plots not harvested during that season. These data show that harvesting every 2 weeks was very unfavorable for Dallis grass. Omitting either the spring or the fall harvests was

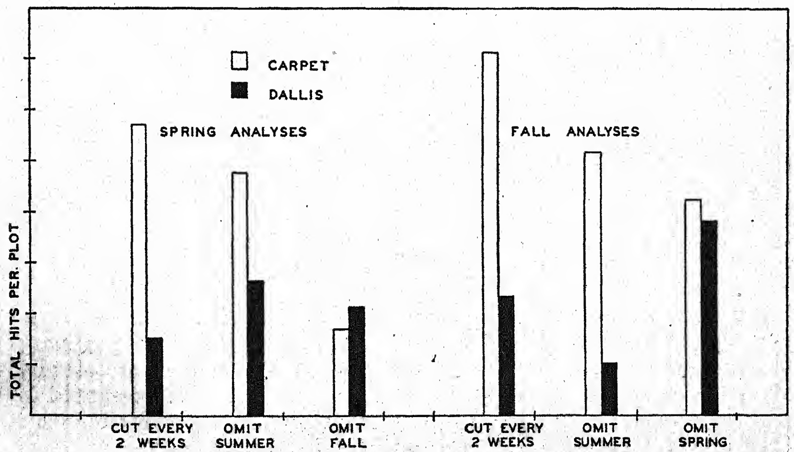


FIG. 7.—Total hits of carpet grass and Dallis grass when grown under different systems of management. Lynchburg fine sandy loam, 1943.

most favorable for Dallis grass, and under such systems of management the quantity of the two grasses was approximately the same. Since botanical analyses were not made on the same plot both seasons, it is not possible to compare the behavior of the grasses under the two management systems. Omitting the two summer cuttings was conducive to an upright growth of the Dallis grass. There were few basal leaves and, consequently, the fall botanical analyses indicated less Dallis grass.

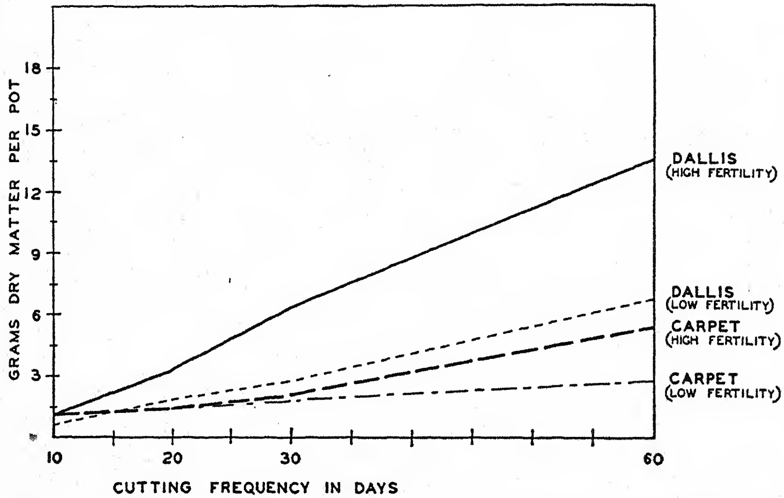


FIG. 8.—Yield of top growth of Dallis grass and carpet grass when grown in the greenhouse at two soil fertility levels and four cutting treatments.

GREENHOUSE STUDIES

The behavior of Dallis grass and carpet grass to defoliation treatments under greenhouse conditions is shown in Figs. 8 and 9. There was a differential response to fertility levels and to defoliation in both the top and root growth. Under a low fertility level and frequent defoliation treatment, Dallis grass yielded no more top or root growth than carpet grass. The response to the high fertility level was greater for both grasses under less severe defoliation treatments, but Dallis grass was superior to carpet grass in a high fertility-less severe defoliation environment. The differential response in yield of root growth was greater than for the yield of top growth.

DISCUSSION

Farmers have reported that carpet grass pastures are unsatisfactory, either for beef or dairy cattle. Observations over eastern North Carolina have indicated that carpet grass pastures are usually almost pure stands of carpet grass. Population data not presented in this paper also show that legumes grow better in association with Dallis grass than with carpet grass. Results from these experiments indicate that the yield of Dallis grass was greater than that of carpet grass, but that both were low.

No explanation is offered for the poor growth of lespedeza during 1942 and 1943. The plants showed potash deficiency symptoms during 1943, but the white clover would be expected to be more sensitive to potash levels than lespedeza. The competition of the carpet grass with the lespedeza is not the explanation because in an adjacent area all of the carpet grass was removed by hand roguing and the growth of of lespedeza was also poor.

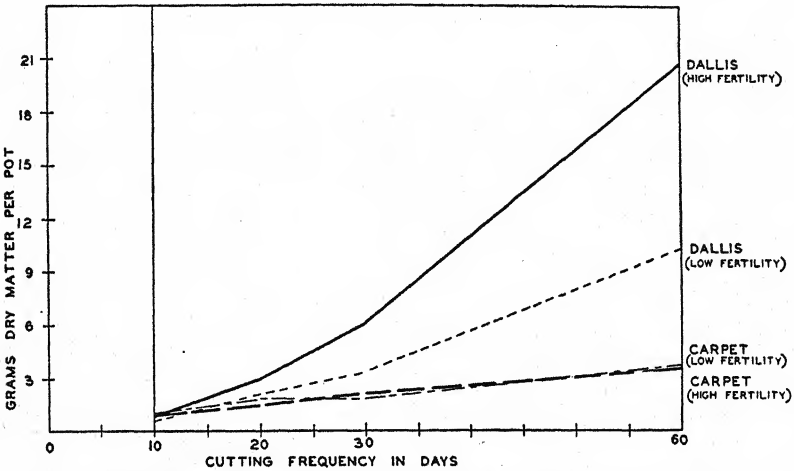


FIG. 9.—Yield of root growth of Dallis grass and carpet grass when grown in the greenhouse at two soil fertility levels and four cutting treatments.

Although the differences were not large enough for statistical significance in all cases, there was a tendency for a grass-legume association to respond to nitrogen fertilization in the early age of the sward. Once a satisfactory legume was established, regardless of whether it was a perennial as white clover or a winter annual as low hop clover, the yields attained were as great from the mineral fertilizers as from the complete fertilizer. The response to the fertilizer treatment would appear to be affected by both the type of vegetation and the age of the sward. It was during the summer and fall that the greatest responses were realized from nitrogen applications. Since Dallis grass is normally making its greatest growth during the summer and early fall, applications of nitrogen, as made in these experiments, will not provide additional forage in the spring when the grazing needs are most critical. A combination of Dallis grass with low hop clover for early grazing and Dallis grass and white clover for summer and fall grazing, in which both would be fertilized with superphosphate, muriate of potash, and limestone, would seem to be more economical.

The necessity of a high fertility level for Dallis grass is shown in both the field and greenhouse studies. This behavior was reflected in the response to fertilization and the response to the association with the legumes.

Dallis grass is more sensitive to defoliation than carpet grass. This

differential behavior can perhaps be explained from both a morphological and physiological point of view. Since Dallis grass is an upright bunch grass, very little photo-synthetic area remains after frequent defoliations. New growth is initiated, therefore, at the expense of previously stored reserves. Carpet grass is a decumbent sod-forming grass. Considerable leaf surface remains after frequent defoliation. Dallis grass also produces more vegetative growth than does carpet grass. Other investigators have found that frequent defoliations are more effective in reducing yields under conditions favoring rapid growth. The management studies have indicated that either a spring or a fall rest period is beneficial to Dallis grass.

SUMMARY

The behavior of Dallis grass and carpet grass in pure stands and in combinations with legumes has been investigated under six soil fertility levels on a well-drained and on a poorly drained Coastal Plain soil. Dallis grass and carpet grass have also been grown in pure stands under greenhouse conditions at two soil fertility levels and under four frequencies of defoliation. Summarizing the results:

1. Dallis grass was more productive than carpet grass.

2. Legumes in combination with the grasses were essential for satisfactory yields.

3. A mixture of Dallis grass and low hop clover produced the greatest yield of any seeding combination during April and May.

4. The response to nitrogen fertilization was greater for Dallis grass than for carpet grass. There was little response of grass-clover combinations to commercial nitrogen after legumes were established.

5. Dallis grass was more sensitive to defoliation than carpet grass. The yields of the former were always inversely related to the frequence of defoliation.

6. The extent to which Dallis grass can compete with carpet grass in permanent pasture was affected by available nutrients, the presence of legumes, and the frequency of cutting. .

LITERATURE CITED

1. Blaser, R. E., and Stokes, W. E. The chemical composition, growth, and certain deficiency symptoms of carpet grass, *Axonopus Affinis*, as affected by lime and fertilizer mixtures. Jour. Amer. Soc. Agron., 34:765–768. 1942.
2. Bledsoe, R. P., and Sell, O. E. Permanent pastures. Ga. Agr. Exp. Sta. Bul. 207. 1940.
3. Mayton, E. L. Permanent pastures studies on upland soil. Ala. Agr. Exp. Sta. Bul. 243. 1935.
4. Ritchey, G. E., and Henley, W. W. Pasture value of different grasses alone and in mixtures. Fla. Agr. Exp. Sta. Bul. 289. 1936.
5. Robinson, R R., and Pierre, W. H. Response of permanent pastures to lime and fertilizer. W. Va. Agr. Exp. Sta. Bul. 269. 1938.
6. ————, ————. The effect of nitrogen fertilization of permanent pastures on seasonal distribution of yields and on nitrogen recovery in the herbage. Jour. Amer. Soc. Agron., 34:747–764. 1942.
7. Smalley, H. R., and Engle, Robert H. Fertilizer use and its effect on crops in 1942. The Fert. Rev., 18: July–Aug.–Sept. 1943.
8. Tinney, F. W., Aamodt, O. S., and Ahlgren, H. L. Preliminary report of a study on methods used in botanical analyses of pasture swards. Jour. Amer. Soc. Agron., 29:835–840. 1937.

REMOVAL OF NUTRIENTS FROM THE SOIL BY CROPS AND EROSION[1]

O. R. NEAL[2]

CONSIDERABLE attention has been given to erosion losses in terms of pounds or tons of soil per acre and inches or acre-feet of run-off water. Less attention has been given to the physical and chemical properties of the eroded material and its similarity or dissimilarity to the original soil. It is usually assumed that soil is removed bodily in the erosion process. In cases of extremely heavy erosion losses and of gully formation this assumption may be correct. On extensive areas of crop land, however, where sheet erosion represents the major loss, there is evidence that the erosion process may be highly selective.

Middleton, Slater, and Byers (5)[3] have reported that in cases where erosion losses are small the eroded material contains a higher percentage of fine mineral particles and organic matter than does the original soil. Pierre (10) points out the fact that soil phosphorus is found chiefly in the finer particles and that erosion losses of this element are often large. Lipman and Conybeare (4) state that phosphorus, potassium, calcium, and sulfur are removed from the soil to a greater extent through erosion than through the harvesting of crops. Duley (1), Kohnke (3), Miller (6), Miller and Krusekopf (7), and Rogers (11) have reported that losses of plant nutrients through erosion are often greater than the quantities removed by crops. Scarseth and Chandler (12), working with a soil that is texturally similar to the Collington sandy loam, found that where phosphate fertilizer had been applied for a period of 26 years, 60% of the superphosphate and 82% of the rock phosphate had been lost through erosion. Earlier work on the analysis of eroded material from the areas concerned in this report has been reported by Knoblauch, Kolodny, and Brill (2) and by Neal (9).

A detailed study has been made of the physical and chemical nature of the material eroded from variously treated plot areas on the Marlboro Soil Conservation Experiment Station, located near the village of Marlboro, N. J. This station is operated cooperatively by the New Jersey Agricultural Experiment Station and the Soil Conservation Service.

The soil is a Collington sandy loam. The method of collecting samples for laboratory use consists of saving a definite fraction of the run-off from each plot during each storm. The aliquots from a single plot for all storms of the year, or other period under study, are combined to form a single sample, which is thus a known fraction of the total erosion loss from a given area for the period under study.

Mechanical analyses of the eroded material for 1942 permits of a comparison of its particle-size distribution with that of the original

[1]Contribution from the Soil Conservation Service, Office of Research, U. S. Dept. of Agriculture; and the New Jersey Agricultural Experiment Station, Rutgers University, New Brunswick, N. J. Received for publication January 11, 1944.

[2]Project Supervisor, Soil Conservation Service.

[3]Figures in parenthesis refer to "Literature Cited", p. 607.

plot soil. Whereas the average percentage of particles that were less than 50 microns in diameter in the surface 6 inches of the original soil of the plots was 15.8, that in the 1942 samples of eroded material was 58. The sand content of the eroded material was approximately one-half that of the original soil. This selective removal of fine particles by erosion tends to make the surface lighter in texture, thereby probably contributing to an increase in the susceptibility of the soil to wind erosion.

Since the eroded material comprises a larger proportion of the smaller, more reactive particles, it would be expected to contain a relatively larger quantity of nutrient elements. Analyses of the eroded soil showed that it contained 4.7 times as much organic matter, 5.0 times as much nitrogen, 3.1 times as much P_2O_5, and 1.4 times as much K_2O as the original soil.

The increased content of organic matter doubtless results in part from the action of the water in floating off leaves and other organic residues from the surface of the soil. But eroded material from areas that were free of vegetation has also been found to contain more organic material than the remaining soil. The nitrogen losses are more or less directly proportional to those of the organic matter. The phosphorus content of the eroded material varies in approximately the same manner as the concentration of fine particles. (Scarseth and Chandler (12) have shown that phosphorus, and particularly the phosphate fixed in the soil from fertilizer, is largely contained in the clay fraction.) The increase in total potassium contained is less than the increase in fine particles. It is known that a considerable portion of the potassium in this soil occurs as glauconite or greensand. The data suggest the possibility that glauconite particles may be passed over in the erosion process in a manner similar to that with sand grains. The eroded material, therefore, contains relatively more of the potassium that is associated with fine particles and less of that occurring as glauconite. This view is substantiated by the results obtained in the study of the availability nutrient elements in the eroded material.

Studies on availability, to date, have been limited to the chemical laboratory. Practically all of the nitrogen is in organic form. The total quantity of phosphoric acid and potash in the original soil and in the eroded material, and the availability as determined by the Morgan method (8), are shown in Table 1.

The phosphoric acid content of the eroded material was approximately 3 times that of the original soil. The percentage availability was nearly the same for the two materials. Since the total quantity of phosphoric acid was 3 times greater in the eroded material than in the original soil, the amount that was available varied in the same manner.

The actual quantity of potash in the eroded material was 1.4 times that in the original soil. The availability of the potash removed by erosion, however, was nearly 4 times that of the potash of the original soil. The eroded material, therefore, contained 5.4 times the percentage of available K_2O as did the original soil.

TABLE 1.—*Content and availability of P_2O_5 and K_2O in original soil and in eroded material.*

Item	Original soil, %	Eroded material, %
Total K_2O	1.67	2.39
Available K_2O, proportion of total	2.73	10.29
Total P_2O_5	0.32	1.00
Available P_2O_5, proportion of total	1.15	1.14

$$\frac{\text{Available in eroded material}}{\text{Available in soil}} = 5.4 \text{ for } K_2O \text{ and } 3.1 \text{ for } P_2O_5$$

The actual quantities of total nitrogen, phosphoric acid, and potash lost through erosion were determined, as described above, by analysis of aliquot samples of eroded material. The amounts of these nutrients removed with tomatoes (fruit only) and sweet corn (ears only) were calculated from Van Slyke's tables.

A comparison of the quantities of total nitrogen, phosphoric acid, and potash removed by tomatoes with the quantities removed by erosion during the growth of the crop is shown in Fig. 1. Obviously all of the nutrients removed with the crop are in an available form, while the availability of the material removed by erosion, as shown above, amounts to 1.14% for P_2O_5 and 10.29% for K_2O. The values as shown in Fig. 1, however, represent the total quantity of nutrient elements lost from the area. These are the values that must be taken into account in arriving at a balance sheet for fertilizer treatments. It has been pointed out (12) that the accumulation of phosphate even in relatively insoluble forms is desirable. Under good soil management practices, such accumulations may slowly become available and the need for phosphate fertilization be gradually diminished.

It should be kept in mind in connection with Figs. 1 and 2 that the values for nutrients removal by crops represent available material, while the values for erosion represent total quantity of nutrient elements without regard to availability.

Where no conservation practices or treatments were in effect, the amounts of phosphoric acid and potash lost through erosion were larger than the amounts removed in the tomatoes. The loss of phosphoric acid in the eroded material was more than twice that by crop removal. The loss of nitrogen in the eroded material was less than one-third that in the crop. When tomatoes were grown on an area that had been cover-cropped during several immediately preceding winter seasons, the removal of nutrients in the tomatoes was higher due to an increased yield, whereas the erosion losses were somewhat lower. Even under these conditions, however, the losses of nutrient elements by erosion were considerable, the loss of phosphoric acid being about equal to the amount contained in the crop and that of the potash a little more than half the amount removed in the crop. The nitrogen loss in this latter case was comparatively low.

Fig 2. shows corresponding data for a sweet corn crop. The results from the treated and untreated areas are comparable to those with the tomato crop, but the erosion losses were somewhat smaller and those by crop removal considerably less than in the case of the tomatoes. The data in Table 2 show the crop yields and soil losses on which these results are based.

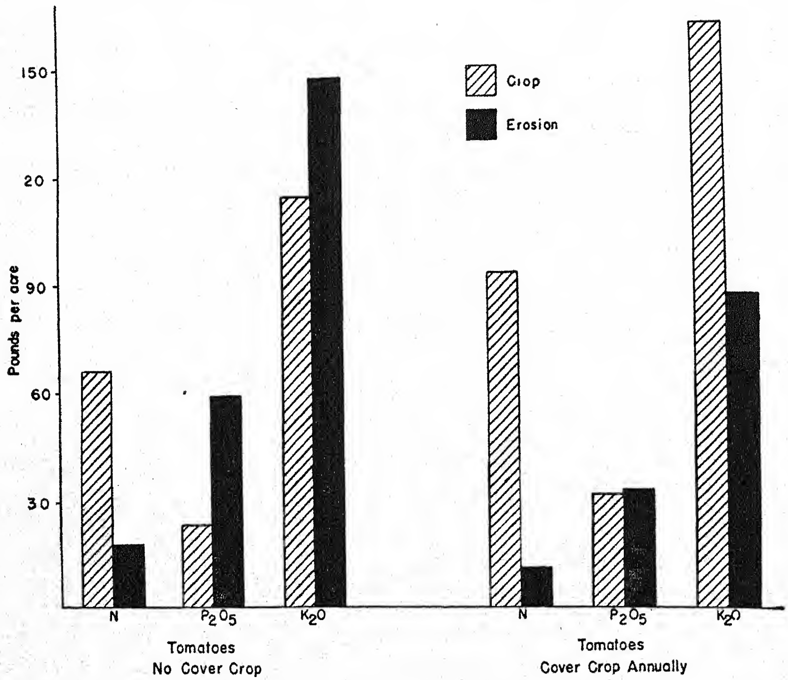


FIG. 1.—Annual removal of total N, P_2O_5, and K_2O from the soil by a tomato crop and by erosion.

TABLE 2.—*Crop yields and erosion losses from areas with and without cover crops.*

Crop	Treatment	Yield, tons per acre	Soil loss, lbs. per acre
Tomatoes	No cover crop	16.6	6,270
Tomatoes	Cover crop	23.2	3,860
Sweet corn	No cover crop or manure	3.96	4,090
Sweet corn	Cover crop and manure	5.93	2,310

The crop yields, and hence the removal of nutrients with the crop, compare favorably with those obtained in other localities. The soil losses, however, are quite small in comparison with those that occur from cultivated land in other sections of the country. Even under these

conditions, the loss of plant nutrient materials by erosion is significant. Where tomatoes were grown on an area without conservation practices, the acre loss by erosion amounted to 18 pounds of total nitrogen, 59 pounds of total P_2O_5, and 147 pounds of total K_2O. This is equivalent in amount to an annual application of approximately 500 pounds per acre of a 4–12–30 grade of fertilizer. The quantities of nutrients removed from the soil during the season both by the crop and by erosion amounted to 84 pounds of nitrogen, 82 pounds of P_2O_5,

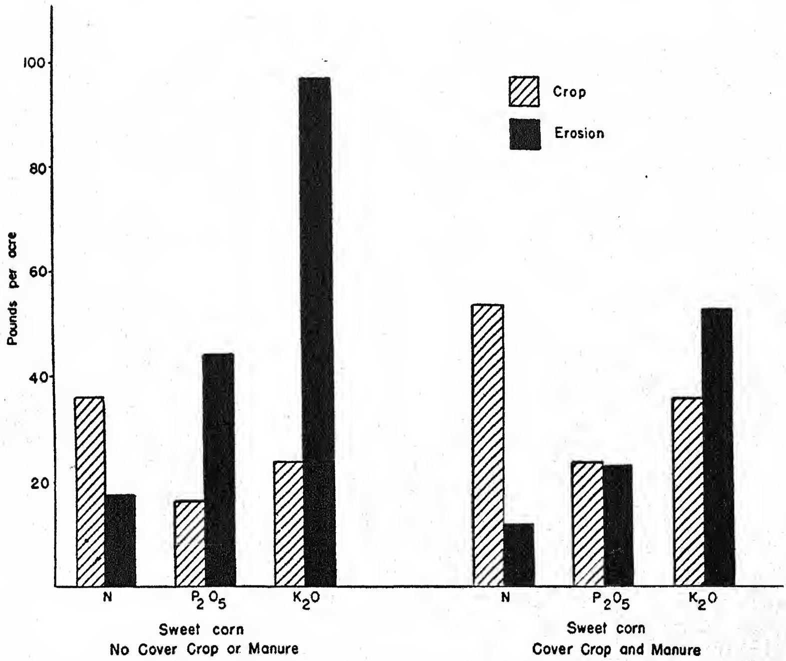


FIG. 2.—Annual removal of total N, P_2O_5, and K_2O from the soil by a sweet corn crop and by erosion.

and 263 pounds of K_2O per acre. An application of 1,000 pounds of 4–12–8 fertilizer per acre would fall far short of furnishing as much nitrogen or potash as was removed during the year. In areas where erosion losses are larger or where fertilizer applications are smaller, the annual net loss in fertility constituents would be considerably greater than is shown here.

The above figures represent an area where tomatoes were grown on soil that had not been manured or cover-cropped. On the area where a cover crop had been grown during immediately preceding winter seasons, the erosion loss of soil was reduced from 6,270 pounds to 3,860 pounds per acre and the yield of tomatoes was increased from 16.6 to 23.2 tons per acre. Notwithstanding this marked increase in yield, the total amount of phosphoric acid and potash removed by the crop and by erosion was less than that from the untreated area where

the yield was lower but the erosion was more severe. Similar results were obtained on the areas cropped to sweet corn.

These results show that losses of total phosphoric acid and potash through erosion may be equal to and in some cases greatly in excess of those resulting from crop removal. Nitrogen losses by erosion are somewhat lower than those resulting from the harvesting of the crops. From the standpoint of soil management and fertility maintenance, the nitrogen losses, as such, are probably less important than are the losses of organic matter in which it is contained. The nitrogen content of the soil can be increased by growing legume cover crops and plowing them under. This practice contributes materially to erosion control and to the conservation of phosphoric acid and potash. The conservation of plant nutrients is partially responsible for the increased yields of crops that have been shown to result from erosion control.

It is evident that if adequate erosion control were put into effect over a period of years, there would be a great reduction in the loss of nutrient elements from the soil. Possibly present yields could be maintained or even increased without the use of large amounts of fertilizer. This is a matter of considerable importance during the present period of limited fertilizer supplies.

SUMMARY

Results are presented on the analysis of material eroded from Collington sandy loam. The quantities of nitrogen, phosphoric acid, and potash removed by tomatoes and sweet corn, and the quantities removed by erosion during the crop year are shown.

The average content of particles less than 50 microns in diameter in the surface of the original soil amounted to 15.8%. The eroded material contained 58% of these size fractions.

In comparison with the original surface soil, the eroded material contained 4.7 times as much organic matter, 5.0 times as much nitrogen, 3.1 times as much P_2O_5, and 1.4 times as much K_2O.

Chemical studies indicated that the percentage availability of P_2O_5 in the eroded material was equal to that in the soil. Potash in eroded material showed a percentage availability 3.7 times greater than that in the soil.

Erosion losses of nitrogen, in comparison with crop removal, were comparatively small in all cases.

Erosion losses of total phosphoric acid, where no cover crop or other conservation practice was used, were double the quantity removed by tomatoes or sweet corn. Where cover crop or cover crop and manure were used annually, the erosion loss continued to equal the quantity of P_2O_5 removed by either crop.

The removal of total K_2O by erosion, where no conservation practices were employed, exceeded the removal of K_2O by tomatoes and was nearly 4 times as much as the removal by sweet corn. Where conservation practices as shown were employed, the removal of total K_2O by erosion was more than one-half as much as that by tomatoes and continued to exceed the quantity removed from the soil by sweet corn.

LITERATURE CITED

1. DULEY, F. L. The loss of soluble salts in runoff water. Soil Sci., 21:401–409. 1926.
2. KNOBLAUCH, H. C., KOLODNY, L., and BRILL, G. D. Erosion losses of major plant nutrients and organic matter from Collington sandy loam. Soil Sci., 53:369–378. 1942.
3. KOHNKE, HELMUT. Runoff chemistry: an undeveloped branch of soil science. Soil Sci. Soc. Amer. Proc., 6:492–500. 1942.
4. LIPMAN, J. G., and CONYBEARE, A. B. Preliminary note on the inventory and balance sheet of plant nutrients in the United States. N. J. Agr. Exp. Sta. Bul. 607. 1936.
5. MIDDLETON, H. E., SLATER, C. S., and BYERS, H. G. The physical and chemical characteristics of the soils from the erosion experiment stations. Second Report. U.S.D.A. Tech Bul. 430. 1934.
6. MILLER, M. F. Waste through soil erosion. Jour. Amer. Soc. Agron., 18:153–160. 1926.
7. ————, and KRUSEKOPF, H. H. The influence of systems of cropping and methods of culture on surface runoff and soil erosion. Mo. Agr. Exp. Sta. Res. Bul. 177. 1932.
8. MORGAN, M. F. The universal soil testing system. Conn. Agr. Exp. Sta. Bul. 392. 1937.
9. NEAL, O. R. The influence of soil erosion on fertility losses and on potato yield. Amer. Potato Jour., 20:57–64. 1943.
10. PIERRE, W. H. Phosphorus deficiency and soil fertility. U.S.D.A. Yearbook, 1938:377–396. 1938.
11. ROGERS, H. T. Losses of surface applied phosphate and limestone through runoff from pasture land. Soil Sci. Soc. Amer. Proc., 7:69–76. 1943.
12. SCARSETH, GEORGE D., and CHANDLER, W. V. Losses of phosphate from a light-textured soil in Alabama and its relation to some aspects of Soil Conservation. Jour. Amer. Soc. Agron., 30:361–374. 1938.

POTASSIUM RESPONSE OF VARIOUS CROPS ON A HIGH-LIME SOIL IN RELATION TO THEIR CONTENTS OF POTASSIUM, CALCIUM, MAGNESIUM, AND SODIUM[1]

C. A. BOWER AND W. H. PIERRE[2]

ASSOCIATED with the normal Webster soils of Iowa are numerous small areas of soil which contain 10 to 30 % of Ca and Mg carbonates. Owing to their limited extent, these soils are included with those of the Webster series, but commonly they are referred to as high-lime soils to distinguish them from the normal soils of this series which are neutral or only slightly calcareous. Corn makes good growth and excellent yields on normal Webster soils. On high-lime soils, however, this crop exhibits marked K-deficiency symptoms and gives large responses to K fertilization.

The causes of this K deficiency in corn have been studied in some detail by Allaway and Pierre (1),[3] Stanford, *et al.* (13), and Kelly (10), largely by comparing the chemical composition of the soil, the soil solution, and the corn plants in high-lime and adjacent normal soil areas. The results of these investigators show that, although normal soils usually contain more exchangeable K, the high-lime soils, in many instances, contain as much as 175 to 200 pounds per acre (2,000,000 pounds of soil) of this element in exchangeable form, which amounts are ordinarily considered sufficient for corn on acid soils. Furthermore, their studies show that the soil solution and the corn plants in high-lime soil areas contain unusually high amounts of Ca and Mg as well as low amounts of K, and that the Ca and Mg to K ratios of the soil solution and corn plants are much larger in high-lime than in adjacent normal soil areas. It was also shown that the high Ca and Mg contents of corn on high-lime soils were decreased by the application of K fertilizer. In view of these findings, as well as others (2, 7, 11) concerning the effects of high concentrations of Ca and Mg on plant absorption of K from culture solutions, these investigators were led to believe that the high Ca and Mg contents of the soil solution of high-lime soils have a repressive effect on K absorption by corn. Pierre and Bower (12) have suggested that this repressive effect is probably accentuated by the high NO_3-N contents and high pH values of these soils.

While K deficiency in corn grown on high-lime soils is usually extreme, it is only rarely that deficiency symptoms are noted in crops which absorb large amounts of Ca and Mg in relation to K, such as sweet clover. This observation suggests that the repressive effects of high concentrations of Ca and Mg on K absorptions by different crops varies according to the amounts of Ca and Mg which they absorb in relation to K. To test this hypothesis, the K response of seven different

[1]Journal paper J-1181 of the Iowa Agricultural Experiment Station, Ames, Iowa, Project 624. This investigation was supported in part by funds provided by the American Potash Institute, Inc. Received for publication February 10, 1944.
[2]Research Assistant Professor and Research Professor of Soils, respectively.
[3]Figures in parenthesis refer to "Literature Cited", p. 614.

crops varying widely in their normal Ca and Mg contents were determined on a K-deficient high-lime soil under greenhouse conditions, and the crops analyzed for their contents of K, Ca, Mg, and Na. For comparative purposes, the K, Ca, Mg, and Na contents of the seven crops grown on a normal Webster soil were also determined. The chemical composition data were then related to the response data.

EXPERIMENTAL

The high-lime Webster soil was obtained from the untreated plots of a fertilizer experimental field located on the Andrew Goehring farm, Webster County, Iowa. A side-dressing of 200 pounds of 0–0–50 fertilizer per acre increased the yield of corn from 23.9 to 53.9 bushels per acre in 1942. This soil has a $CaCO_3$ equivalence of 30.9% and its contents of exchangeable K and Na are, respectively, 0.17 and 0.30 M.E. per 100 grams. The normal Webster soil was obtained from an unfertilized area of the Northern Iowa Experimental Association farm, Hancock County, Iowa. Previous experiments had shown that this soil does not respond to K fertilization under greenhouse conditions. The pH value of this soil is 6.2 and its contents of exchangeable Ca, Mg, K, and Na are, respectively, 26.4, 7.0, 0.42, and 0.54 M.E. per 100 grams.

The crops were grown in 2-gallon pots containing 15 pounds of soil and three replications were used. In the first experiment conducted with the high-lime soil, corn, flax, soybeans, and sweet clover were planted on June 30, 1942, and harvested 45 days later, except the sweet clover which was allowed to grow 90 days. The larger roots were then removed from the harvested pots and, after combining all soil which had received the same K fertilizer treatment, it was repotted. In a second experiment, the soil was planted to oats, sorghum, and buckwheat on September 5, 1942, and the crops were harvested 45 days later. In the experiment using the normal Webster soil, all crops were planted on May 11, 1943, and harvested after 45 days of growth.

In preparing plants for chemical analysis, they were dried at 75° C., ground in a Christy-Norris mill, and wet-ashed by the method of Gieseking, *et al.* (8). Exchangeable cations were leached from the soils with neutral normal ammonium acetate solution, and the soil solution was displaced by the method of Burd and Martin (6). Ca and Mg were estimated by the A.O.A.C. methods (3), K according to Brown, *et al.* (5), and Na by the procedure of Broadfoot and Browning (4). pH was measured with a Coleman pH meter equipped with a glass electrode.

RESULTS

The responses of the different crops to the two rates of application of K fertilizer are given in Table 1. It will be noted that there was a wide range in the response of the various crops. Corn and sorghum showed the greatest response to K fertilization, whereas sweet clover did not give a significant response and buckwheat yields were actually decreased. These responses for corn, sorghum, soybeans, flax, oats, and sweet clover are in general agreement with observations made on their growth in the field on high-lime soils. No field information is available on buckwheat.

The data on the effect of K fertilization on the K, Ca, Mg, and Na contents of the crops are also given in Table 1. In agreement with previous results with corn (13), the applications of K fertilizer materially increased the K contents of the crops and decreased the contents of other elements. As shown in Table 2, the decrease was in general greater with Na than with Mg and with Mg than with Ca. The latter indicates that the low K absorption by crops grown on high-lime soils may be due more to Mg than to Ca "antagonism" or "replacement",

TABLE 1.—*The effect of K fertilization on the yields and K, Ca, Mg, and Na contents of various crops grown in the greenhouse on high-lime Webster loam soil.*

KCl fertilizer in lbs. of K_2O per acre*	Yield per pot, grams	K response, %	Chemical composition, M.E. per 100 grams				$\frac{Ca+Mg}{K}$	(Ca+Mg)−K, M.E. per 100 grams
			K	Ca	Mg	Na		
1st Experiment, Corn								
0	4.5	—	10.9	58.0	104.7	<1	14.9	151.8
150	6.8	51.5†	16.5	56.8	92.0	<1	9.0	132.3
450	9.6	111.0†	69.2	46.7	53.3	<1	1.4	30.8
1st Experiment, Flax								
0	2.7	—	7.4	111.3	65.0	43.5	—‡	—‡
150	3.1	14.8	14.4	99.7	54.3	30.5	—‡	—‡
450	3.4	25.9†	31.6	90.8	48.0	17.2	—‡	—‡
1st Experiment, Soybeans								
0	7.9	—	15.1	92.1	141.0	<1	15.4	218.0
150	10.3	30.4†	21.6	93.2	119.0	<1	9.8	190.6
450	11.7	48.1†	45.3	88.4	64.3	<1	3.4	107.4
1st Experiment, Sweet Clover								
0	17.0	—	11.3	171.0	79.0	<1	22.1	238.7
150	18.3	8.0	15.7	167.0	58.0	<1	14.3	209.3
450	18.0	5.9	32.0	146.3	36.5	<1	5.7	150.8
2nd Experiment, Sorghum								
0	6.5	—	13.7	64.1	72.0	<1	10.0	122.4
150	9.3	42.0†	29.8	49.9	55.0	<1	3.5	75.1
450	14.7	124.3†	49.1	35.2	33.5	<1	1.4	19.6
2nd Experiment, Oats								
0	6.8	—	24.1	27.2	36.0	25.4	—‡	—‡
150	8.8	29.3†	40.6	24.4	29.0	19.1	—‡	—‡
450	10.9	59.0†	56.3	22.0	22.0	10.2	—‡	—‡
2nd Experiment, Buckwheat								
0	8.0	—	42.2	179.5	179.0	<1	8.5	316.3
150	7.6	−5.6	60.8	177.9	164.0	<1	5.6	281.1
450	6.8	−15.3†	91.8	154.8	139.0	<1	3.2	202.0

*In addition, all soil received $CaH_4(PO_4)_2$ at the rate of 200 lbs. per acre and N was supplied in the form of NH_4NO_3 solution as needed.
†Significant at 5% level.
‡Not calculated since the crop absorbs appreciable amounts of Na.

The effect of Na on K absorption by crops on high-lime soils is probably quite different, however, from that of Ca or Mg, for Na can to some extent replace K in the K nutrition of some crops (9). Therefore, with "sodium crops", i.e. crops that absorb considerable Na, the relatively high absorption of Na from these soils probably counterbalances to some extent the detrimental effect on plant growth that results from too high an absorption of Ca and Mg in relation to K.

In the present experiment, the small responses from K fertilization obtained with oats and especially with flax, as compared with corn

TABLE 2.—*Changes in the K, Ca, Mg, and Na contents of the various crops as a result of K fertilization.**

Crop	KCl fertilizer in lbs. of K_2O per acre	Increase in K, M.E. per 100 grams	Decrease in Ca, M.E. per 100 grams	Decrease in Mg, M.E. per 100 grams	Decrease in Na, M.E. per 100 grams
Corn	150	5.6	1.2	12.7	—
	450	58.3	11.3	51.4	—
Flax	150	7.0	11.6	10.7	13.0
	450	24.2	20.5	17.0	26.3
Soybeans	150	6.5	0.0	22.0	—
	450	30.2	3.7	76.7	—
Sweet clover	150	4.4	4.0	21.0	—
	450	20.7	24.7	42.5	—
Sorghum	150	16.1	14.2	17.0	—
	450	35.4	28.9	38.5	—
Oats	150	16.5	2.8	7.0	6.3
	450	32.2	5.2	14.0	15.2
Buckwheat	150	18.6	1.6	15.0	—
	450	49.6	24.7	40.0	—

*Calculated from data given in Table 1.

and sorghum, can probably be explained on this basis. Furthermore, it would appear that flax responds less than oats because Na substitutes for K to a greater extent in the former crop. A preliminary study indicates that most high-lime Webster soils contain about 0.3 M.E. of exchangeable Na per 100 grams.

The data presented in Table 1 indicate that there is a significant relationship between the K response of the five "non-sodium crops"—corn, sorghum, soybeans, sweet clover, and buckwheat—and their contents of K, Ca, and Mg. Those crops that absorb or require for normal growth a high amount of K relative to Ca and Mg show the greatest response to K fertilization, whereas those that absorb a large amount of Ca and Mg in relation to K show little or no response to K fertilization. This relationship is brought out in the $\frac{\text{“Ca + Mg”}}{\text{K}}$ and the "(Ca + Mg) − K" values given in the last two columns of Table 1. Corn and sorghum which showed the greatest K-deficiency symptoms and responded the most to K fertilization had the lowest "(Ca + Mg) − K" values. The five crops in order of decreasing response had "(Ca + Mg) − K" values when grown on the soil receiving the high rate of potassium fertilizer as follows: Sorghum, 19.6; corn, 30.8; soybeans, 107.4; sweet clover, 150.8; and buckwheat, 202.0. The $\frac{\text{“Ca + Mg”}}{\text{K}}$ values of the crops grown on the soil fertilized at the high rate showed the same correlation with percentage K response, except

in the case of buckwheat where luxury consumption of K resulted from the large application of K fertilizer.

Because of the possibility that there was luxury consumption of K by the crops fertilized at the rate of 450 pounds of K_2O per acre, it was thought desirable to determine the K, Ca, and Mg contents of these crops when grown on a normal Webster soil that showed no response to K fertilization and contained 0.42 M.E. of exchangeable K per 100 grams. The plants were grown to about the same stage of growth as in the previous experiments, and were analyzed for K, Ca, Mg, and Na. The data are presented in Table 3.

TABLE 3.—*The K, Ca, Mg, and Na contents of various crops grown in the greenhouse on a normal Webster loam soil.**

Crop	Chemical composition, M.E. per 100 grams				$\frac{Ca+Mg}{K}$	(Ca+Mg)–K, M.E. per 100 grams
	K	Ca	Mg	Na		
			Non-sodium Crops			
Corn.......	41.1	18.9	35.0	<1	1.3	12.8
Sorghum....	56.9	40.0	47.5	<1	1.5	30.6
Soybean....	40.1	76.9	67.5	<1	3.6	104.3
Sweet clover.	30.1	131.3	42.7	<1	5.8	143.9
Buckwheat..	82.2	112.4	137.5	<1	3.0	167.7
			Sodium Crops			
Oat.........	66.2	24.6	27.0	11.8	—†	—†
Flax........	66.5	81.7	39.5	16.1	—†	—†

*The soil received $CaH_4(PO_4)_2$ at the rate of 200 lbs. per acre and N was supplied in the form of NH_4NO_3 solution as needed.

†Not calculated since the crop absorbs appreciable amounts of Na.

It will be noted that, in general, the relationships between the amount of the different elements absorbed by the various crops are quite similar to those found in the crops grown on the high-lime soil receiving the high rate of K fertilizer (Table 1). This is especially true for the $\frac{\text{“Ca + Mg”}}{\text{K}}$ values. The significant fact again shown is that both the $\frac{\text{“Ca + Mg”}}{\text{K}}$ and the "(Ca + Mg) – K" values of the five "non-sodium crops" show a close relationship to their percentage response to K fertilization, as shown in Table 1. This correlation is more definite for the "(Ca + Mg)–K" values which are not so much influenced by wide variations among the various crops in one or more of the elements as are the $\frac{\text{“Ca + Mg”}}{\text{K}}$ values.

DISCUSSION

The data obtained in this investigation explain, at least in part, the variations found among different crops in their response to K

fertilization when grown on high-lime soils. As has been previously found (1), the poor growth and low absorption of K by corn on these soils is not due to low amounts of exchangeable K, since corn showed extreme K deficiency on some of these soils which contained over 200 pounds per acre (2,000,000 pounds of soil) of exchangeable K, but rather to the repressive effect on K absorption of high concentrations of Ca and Mg in the soil solution. Several investigators (2, 7, 11) have shown that K absorption by plants growing in culture solutions is depressed when the ratios of Ca and Mg to K in the solution are high. The soil solution, displaced from an uncropped pot of the high-lime soil used in this study which had been incubated for 1 month at approximately optimum moisture content (37.5%), contained 2, 348, 83, and 13 p.p.m., respectively, of K, Ca, Mg, and Na. The Ca +Mg to K ratio of this solution, calculated on a chemical equivalence basis, is 483, a figure which is quite high although not as high as for some high-lime soils (9). In the immediate vicinity of the plant root the Ca and Mg to K ratios of the soil solution no doubt vary according to the relative amounts of the various cations being absorbed by the root. It is quite likely, therefore, that these ratios will be lower in the soil solution surrounding the roots of those crops which absorb large amounts of Ca and Mg in relation to K than around the roots of those crops which absorb less Ca and Mg. According to the findings in culture solution studies, lowering the Ca and Mg to K ratios would permit K to be absorbed more readily. Such reasoning provides a basis for explaining, for example, why buckwheat, sweet clover, and soybeans absorbed larger amounts of K from the soil studied and responded less to K fertilization than corn and sorghum. In the above discussion, it has been assumed that the various cations are absorbed largely from the soil solution. The same reasoning probably applies equally well, however, to the absorption of K from the surface of soil colloids.

It is recognized that the relative amounts of Ca, Mg, and K used by various crops is probably not the only factor which determines their ability to secure K from high-lime soils. Furthermore, it should be recognized that the dominant factors operative in high-lime soils are no doubt different from those operative in K-deficient acid soils. In the latter soils the absorption of K is probably seldom repressed by too high a concentration of Ca and Mg. Therefore, other inherent characteristics of the various crops would determine their relative response to K.

SUMMARY AND CONCLUSIONS

The K response of seven different crops grown on a K-deficient high-lime soil of the Webster series was determined in the greenhouse, using two rates of K fertilization. The crops were analyzed for K, Ca, Mg, and Na in order to determine if the variations in the K response of the different crops on high-lime soils might be explained by differences in their normal absorption of Ca, Mg, and Na in relation to K.

Large responses to K fertilization were obtained with corn and sorghum, whereas only slight to moderate responses were obtained

with flax, oats, and soybeans. Sweet clover gave no response and that of buckwheat was negative. Of the various crops studied, only flax and oats absorbed appreciable amounts of Na. It appears that these crops respond but little to K fertilization because the Na which they absorb substitutes for K in the plant and thereby lowers the crop demand for K.

In the case of those crops which absorb only small amounts of Na, it was found that their K responsiveness on the high-lime soil studied varied with their normal contents of Ca and Mg in relation to K. Sweet clover and buckwheat, which gave no K response, are crops which ordinarily use large amounts of Ca and Mg in relation to K, whereas the highly responsive crops, corn and sorghum, normally use small amounts. Soybeans occupy an intermediate position as regards K response and contents of Ca and Mg.

These results are explained on the basis that (a) K absorption by crops on high-lime soils is repressed by high concentrations of Ca and Mg in the soil solutions, and (b) that those crops which require considerable amounts of Ca and Mg for normal growth show low response to K fertilization because they lower the ratios of Ca and Mg to K in the soil solution sufficiently to reduce or remove the repressive effects of Ca and Mg on K absorption.

LITERATURE CITED

1. ALLAWAY, H., and PIERRE, W. H. Availability, fixation, and liberation of potassium from high-lime soils. Jour. Amer. Soc. Agron., 31:940–953. 1939.
2. ALTON, F., and ORTH, H. Wasserkulturversuche zur Kalk-kalifrage. Ernähr. Pflanze, 36:13–16. 1940.
3. ASSOCIATION OF OFFICIAL AGRICULTURAL CHEMISTS. Official and Tentative Methods of Analysis. Washington, D. C. Ed. 5. 1940.
4. BROADFOOT, W. M., and BROWNING, G. M. Factors influencing the determination of sodium in plant material. Jour. Assoc. Off. Agr. Chem., 24:916–926. 1940.
5. BROWN, D. S., ROBINSON, R. R., and BROWNING, G. M. Determination of small amounts of potassium. Ind. and Eng. Chem., Anal. Ed., 10:652-654. 1936.
6. BURD, J. S., and MARTIN, J. C. Water displacement of soils and the soil solution. Jour. Agr. Sci., 13:265–295. 1923.
7. DAVIDSON, O. W., and BLAKE, M. A. Nutrient deficiency and nutrient balance in the peach. Proc. Amer. Soc. Hort. Sci., 35:339–346. 1937.
8. GIESEKING, J. E., SNIDER, H. J., and GETZ, C. A. Destruction of organic matter in plant material by the use of nitric and perchloric acids. Ind. and Eng. Chem., Anal. Ed., 7:185–186. 1935.
9. HARTWELL, B. L., and PEMBER, F. R. Sodium as a partial substitute for potassium. R. I. Agr. Exp. Sta. Ann. Rpt., 21:241–283. 1908.
10. KELLY, J. B. Composition of the displaced soil solution and exchangeable potassium content of high-lime soils in relation to potassium deficiency in corn. Master's thesis, Iowa State College, Ames, Iowa. 1941.
11. LUNDEGARDH, H. Die Nährstoff aufnahme der Pflanze. Jena: Gustav Fischer. 1932.
12. PIERRE, W. H., and BOWER, C. A. Potassium absorption by plants as affected by cationic relationships. Soil Sci., 55:23–36. 1943.
13. STANFORD, G., KELLY, J. B., and PIERRE, W. H. Cation balance in corn grown on high-lime soils in relation to potassium deficiency. Soil Sci. Soc. Amer. Proc., 6:335–341. 1942.

SOME FACTORS AFFECTING THE ESTABLISHMENT OF PERENNIAL GRASS FOR EROSION CONTROL IN EASTERN COLORADO[1]

Jess L. Fults[2]

INTEREST in the regrassing of marginal lands and areas of acute erosion hazards in the Great Plains has been high since the intensive dust storms that occurred between 1934 and 1940. Because of this fact, investigations were initiated in the Central Great Plains by the Soil Conservation Service in cooperation with the Colorado Agricultural Experiment Station to determine the best methods for re-establishing the native grasses, as this appeared to be one of the most effective means of controlling wind erosion over large areas.

The results reported in this paper were obtained from detailed studies made on the Colorado Agricultural Experiment Substation located ¼ mile south of Cheyenne Wells, Colo. This work covered the 3-year period from July 1, 1939, to July 1, 1942. The time covered by these investigations was characterized by wide variations in climatic conditions, especially annual precipitation.

The annual precipitation in 1939 was 12.73 inches, in 1940, 14.91 inches; in 1941, 21.21 inches; and in 1942, 23.68 inches (Table 1).

Table 1.—*Monthly and annual precipitation in inches for the years 1939, 1940, 1941, and 1942 at Cheyenne Wells, Colo.*

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
1939	0.89	1.45	0.54	0.16	2.11	4.01	2.16	0.37	0.50	0.11	0.20	0.25	12.73
1940	0.08	0.21	2.34	0.53	2.11	1.57	1.73	3.35	2.44	0.04	0.17	0.34	14.91
1941	0.17	0.04	0.39	1.87	1.93	2.75	5.05	2.15	5.11	1.19	0.10	0.46	21.21
1942	0.14	0.63	0.08	2.72	0.25	5.15	2.43	3.51	2.85	5.19	0.14	0.49	23.68
Av. 1892 to 1942	0.30	0.51	0.76	1.92	2.23	2.62	2.70	2.37	1.29	0.99	0.51	0.53	16.73

So far as precipitation is concerned, the fall of 1939 was very unfavorable for grass establishment. The springs of 1940 and 1941 were only moderately favorable, while the late summer and early fall of both 1940 and 1941 were very favorable.

The 50-year precipitation record at Cheyenne Wells (1892 to 1942) indicates the mean annual precipitation to be 16.73 inches. This was exceeded during 1941 and 1942 but not during 1939 and 1940. A study of the long-time average monthly totals indicates that the highest precipitation occurs in May, June, July, and August with April and September slightly less. During the periods of these tests, the monthly totals of precipitation were similar to the long-time

[1]Contribution from the Soil Conservation Service, U. S. Dept. of Agriculture, in cooperation with the Colorado Agricultural Experiment Station, Fort Collins, Colo. Received for publication February 16, 1944.

[2]Associate Agronomist, Office of Research, Soil Conservation Service, U. S. Dept. of Agriculture, Amarillo, Tex.

averages in that most of the annual increment occurred between May and September. During 1939, every month (May to September) had less than average precipitation except June; in 1940, August and September were higher than average, the rest lower; in 1941, July, August, and September were higher, the rest lower and in 1942, April June, August, and September were higher and the rest lower than the average.

The factors affecting the establishment of grass that were investigated included type of cover, precipitation, soil moisture, time of planting, depth and method of planting, and weed mowing. Although the studies reported here are preliminary, they should be indicative of results likely to be obtained over longer periods.

REVIEW OF LITERATURE

Savage (9)[3] and Savage and Smith (10) have indicated that revegetation of cultivated land in the southern Great Plains may be advantageously accomplished by planting adapted grasses in medium early spring, in high, dense undisturbed stubble and hay residue left by a preparatory crop of close-drilled sudan grass or other sorghum. This method has been indicated to be necessary in semi-arid districts of the southern Plains where soil blowing prevents the use of fallow.

The factor of "cover" in its relationship to soil and water conservation, rainfall interception, and plant growth in the Great Plains has been investigated by several workers (1, 4, 5, 6), but very little quantitative data are available on the exact relationship between cover and grass seedling emergence, survival, and establishment.

Murphy and Arny (8) have reported on the factor of depth of planting grass seed in five soil types.

METHODS AND MATERIALS

The factor of "cover" in the establishment of perennial grass was studied by measuring the results of planting four grasses and a grass mixture in weeds, mainly Russian thistles, millet stubble, barley stubble, sorghum stubble, sorghum hay residue, and on fallow. At the same time, the influence of "cover" was studied in relation to planting date, depth of planting, and weed mowing. Quantitative data supported by detailed observation were secured by quadrat counts of grass seedling emergence, survival and, establishment. Seedling counts were made on meter-square quadrats to obtain data on germination and first season survival; thereafter, an area-list quadrat method similar to that devised by Culley (3) was used for obtaining data when individual plant counts were no longer accurate. Precipitation and temperature data were secured from U. S. Weather Bureau rain gauges and thermometers located on the experiment station farm at Cheyenne Wells, Colo. Data on soil moisture in its relationship to grass seedling establishment were obtained by frequent soil moisture tests made at such intervals as were thought desirable. In all cases, soil moisture tests were made at planting time, midsummer, the end of the growing season, and at other times whenever moisture appeared to be a critical factor.

The types of cover studied were (a) weeds, mainly Russian thistles (Fig. 1); (b)row crop sorghum stubble; (c) drilled sorghum stubble; (d) row crop hay residue; (e) drilled sorghum hay residue; (f) barley stubble (Fig. 2); and (g) millet stubble and sudan grass stubble. Fallow or clean tilled land was used as a check. Spring plantings were made in weeds, sorghums, and on fallow, and fall plantings in weeds, barley, millet, and on fallow. Fallow plots were kept clean with a deep furrow drill in all cases. The fall 1939 plots were fallowed during the summer of 1938 and 1939 prior to the first plantings in September, 1939. The spring 1940 and 1941 fallow plots were tilled twice a year during the growing seasons of 1939 and 1940, respectively. On most plots, sorghums preceded fallow operations. Plantings were made in the spring of 1940, the late summer and early fall of 1940, and

[3]Figures in parenthesis refer to "Literature Cited", p. 625.

in the spring of 1941. All plantings were made in replicated 1/20-acre plots except for weed cover which were 1/40-acre plots.

The grasses used were blue grama, *Bouteloua gracilis* (H.B.K.) Lag., side-oats grama, *Bouteloua curtipendula* (Michx.) Torr., western wheatgrass, *Agropyron smithii* Rydb., buffalo grass, *Buchloe dactyloides* (Nutt.) Engelm., and a grass mixture consisting of these same species but mostly blue grama and western wheatgrass.

The planting rates per acre of "field-run" seed used were blue grama 18.8 pounds, side-oats grama 57.5 pounds, western wheatgrass 18.3 pounds, buffalo grass 19.9 pounds, and the grass mixture 21.6 pounds. In terms of 100% viable seed (rate × purity × germination at planting time), these rates were blue grama 4.3 pounds per acre, side-oats grama 1.8 pounds, western wheatgrass 7.1 pounds, and buffalo grass 5.2 pounds. The grass mixture on "field-run" basis consisted of 4 parts by weight of blue grama, side-oats grama 2 parts, western wheatgrass 2 parts, and buffalo grass 1 part. The total 100% viable seed amounted to 6.06 pounds per acre. The average purity of the seeds used were blue grama 31.3%, side-oats grama 3.0%, western wheatgrass 60.7%, buffalo grass 47.9%, and the grass mixture 37.5%. The average germination of the blue grama used was 74.3%, side-oats grama 52.3%, western wheat grass 63.6%, buffalo grass 56.3%, and the grass mixture 74.7%.

RESULTS

EFFECT OF COVER

Quadrat counts on the spring plantings made in 1940 and 1941 and in the fall of 1940 indicated that "cover" was not the determining factor in emergence of grass seedlings. Counts made in the summer of 1940 showed that the best emergence of western wheatgrass and buffalo grass was obtained in drilled sorghum cover (Coes sorgo), side-oats grama in row crop broom corn stubble, blue grama on fallow, and the grass mixture in sudan grass stubble. Counts made during the summer of 1941 showed results which were different for every grass and the grass mixture from those of 1940 (Table 2). The counts made in the fall of 1940 were similar to those of the springs of 1940 and 1941 in that no one type of cover gave the best emergence for all grasses (Table 2).

Each figure shown in Table 2 is the average of three quadrat readings, one from each plot where the seed was broadcast, drilled ½ inch deep, and drilled 1 inch deep. The weeds used in both 1940 and 1941 were predominantly Russian thistle of very similar densities and character. The spring fallow plots were fallowed with a deep furrow cultivator one growing season prior to grass planting, i.e., in the 1939 and 1940 seasons. The fall 1940 fallow plot was fallowed during both the summers of 1939 and 1940. The barley and millet stubble used for fall of 1940 plantings grew during the summer of 1940. Both volunteered strongly in the fall of 1940 but died out the following winter.

TIME OF PLANTING

The factor of time of planting was evaluated by studying the results of grass plantings made in the early and late fall of 1939 (September 15 and November 15), spring, late summer and early fall of 1940 (April 15, August 15, and September 15), and spring of 1941. At each date of planting, blue grama, side-oats grama, buffalo grass, western wheatgrass, and a mixture of these same species were each planted in all different types of cover at a depth of ½ inch, 1 inch, and broadcast.

TABLE 2.—*Type of cover and emergence of four grasses and a grass mixture.*

Grass species	No. of plants per square meter						
	Weeds	Coes sorgo	Sudan grass	Broom corn	Fallow	Barley stubble	Millet stubble
			Spring, 1940				
Western wheatgrass	11	64	14	23	30	—	—
Side-oats grama	68	23	61	121	43	—	—
Buffalo grass	2	17	6	0	8	—	—
Blue grama	223	39	61	71	365	—	—
Grass mixture	5	20	100	75	64	—	—
Total	309	163	242	290	510	—	—
			Spring, 1941				
Western wheatgrass	0	21	0	12	119	—	—
Side-oats grama	0	3	0	3	9	—	—
Buffalo grass	0	2	0	7	7	—	—
Blue grama	50	77	0	50	46	—	—
Grass mixture	84	56	0	24	39	—	—
Total	134	159	0	96	220	—	—
			Fall, 1940				
Western wheatgrass	16	—	—	—	107	61	63
Side-oats grama	42	—	—	—	42	59	37
Buffalo grass	0	—	—	—	0	0	0
Blue grama	144	—	—	—	269	196	211
Grass mixture	76	—	—	—	75	97	99
Total	278	—	—	—	493	413	410

Duplicate plots of each planting were made at each date, one of which was subsequently kept mowed as a test of weed control.

For western wheatgrass, the best results were secured from late summer plantings irrespective of character of cover. The same was true of grass mixture plantings and of blue grama. The best buffalo grass stands resulted from fall plantings which germinated the following spring, but equally good stands of side-oats grama were obtained from spring and late summer plantings.

In the grass mixture plantings, the two most successful species were blue grama and western wheatgrass in the final turf. This was expected because of the relative amounts of viable seed used in the seed mixture.

In some cases, very poor initial stands of western wheatgrass and buffalo grass spread to form very good to excellent turfs. In one case, where western wheatgrass was planted on fallow in the extremely dry fall of 1939, there was an average emergence by the spring of 1940 of only 3 seedlings per square meter. By June of 1942, these seedlings had grown and spread until the plot was completely dominated by western wheatgrass. On June 7, 1942, the average number of wheatgrass stems per square meter was 1,037. The season of planting may

be of less importance than supposed, especially with sod-type grasses. For these species it appears more important to time the planting of seed with periods when moisture is favorable rather than planting at some specific period in the spring or fall.

In most of these tests, initial seedling counts of 15 to 20 western wheatgrass plants, 6 to 10 buffalo grass plants, 25 to 30 plants of side-oats grama, and 35 to 40 blue grama plants per square meter were sufficient to develop turfs with densities approximately equal to native vegetation within 2 years. Later observations and measurements made by Hugh G. Porterfield of the Amarillo, Texas, Conservation Experiment Station (unpublished), over a wide area in the Panhandle of Texas and nearby areas in Oklahoma, Kansas, Southeastern Colorado, and northeastern New Mexico show that much fewer plants per square meter than the above have produced a satisfactory cover and forage yield 3 to 4 years after planting.

SEASONAL PRECIPITATION AND SOIL MOISTURE

The only grass planted in the very dry fall of 1939, which emerged to a poor initial stand and then later formed a turf, was western wheatgrass. This planting was made in September but failed to germinate until late March of the next year and then only very poorly. This was due to moisture received as a very wet snow on March 2, 1940. Precipitation received in amounts of 0.10 to 0.25 inch prior to the wet snow was entirely ineffective in starting germination.

Grass plantings made on April 18 to 23, 1940, did not germinate until after May 17, when 1.00 inch of precipitation was received in a slow rain. Emergence of grass seedlings continued satisfactorily because of rains of 0.42 and 0.35 inch on May 27 and 29. Growing conditions continued good until June 9 when a 1.24-inch rain was received, and thereafter until about the last week in June. Thereafter, no effective precipitation was received until August 18, resulting in the death of most grass seedlings.

The most effective precipitation occurred between August 18 and September 30, 1940. After a very hot, dry summer two rains of 1.25 inches and 1.43 inches fell on August 18 and 26 respectively. These two heavy rains were followed by seven lighter rains within 30 days. The result of these unusually favorable moisture conditions was reflected not only in the fall emergence of grass seedlings but also in vigorous growth early the next growing season in 1941.

From the results obtained, correlated to soil moisture data, it appears that a very favorable establishment of grass seedlings can be expected whenever enough precipitation is received to insure a moist soil to a depth of about 24 inches followed or accompanied by approximately 6 weeks of high relative humidity and favorable temperatures. These conditions were best met in these tests in the late summer and early fall of 1940 and, as a result, grass establishment was excellent at that time.

The frequency of the occurrence of moist soil to a depth of 24 inches in eastern Colorado can be judged by an examination of published data (2) from the U. S. Dry Land Experiment Station at Akron,

Colo., since the annual precipitation and its distribution are rather similar to that at Cheyenne Wells (17.18 inches at Akron and 16.73 inches at Cheyenne Wells). For 11 different years from 1908 to 1921, soil moisture tests at Akron showed the soil to be wet to a depth of 24 inches 82% of the time on the date of spring wheat planting on continuously cropped spring wheat land. During the same 11 years, in tests on adjacent plots that were alternately fallowed and cropped to spring wheat the soil was wet to at least 24 inches in every case. These results would indicate that adequate soil moisture for spring grass reseeding can be expected most of the time, and that in periods of deficient rainfall the probability of success could be increased by planting on land fallowed at least one previous growing season. In order to reduce the wind erosion hazard, plantings could be made in August on land fallowed with a deep furrow cultivator during the preceding May, June, and July as was done in certain tests at Cheyenne Wells. By making August grass plantings on the sides and in the furrows of land fallowed in this manner, much of the danger of wind erosion the winter following was reduced in the tests at Cheyenne Wells.

Recent studies by F. G. Ackerman at the Amarillo, Texas, Conservation Experiment Station (unpublished) indicate that the use of the stubble-mulch system of fallow, which leaves a protective crop residue on the surface, may have all the advantages of clean fallow for storing soil moisture plus the advantages of added protection against wind erosion, reduced hazard of crusting at time of seedling emergence, and the possibility of more favorable moisture in the surface 6 inches of soil for at least 2 weeks longer than clean tillage during sustained drought.

The establishment of satisfactory stands of sod-forming grasses, such as western wheatgrass and buffalo grass, can be expected with somewhat less favorable precipitation than is the case with bunch grasses, such as blue grama and side-oats grama, because a few scattered plants of a sod-type grass are able eventually to spread and cover a large area, whereas plants of blue grama and side-oats grama usually spread very slowly either vegetatively or by volunteer seedlings.

Soil moisture was a limiting factor in the establishment of grass stands between May 17 and July 17, 1940. At the time of most critical moisture shortage on July 17, 1940, soil moisture percentages under the several types of cover tested and on clean fallow were not significantly different—all were very low at all depths. The best seedling emergence prior to July 17, 1940, and the best survival later was secured on the fallow plots. The second best emergence was secured in weeds and the second best survival in prepared sudan cover. These facts suggest that the determining factors in survival at times of critical moisture are other than the presence or absence of surface crop or weed residues. Further investigation indicated that the responsible factor may be the total available moisture in the 0 to 24-inch zone at planting time. Moisture samples showed that the fallow and sudan cover plots had significantly higher moisture content at planting time in the 0- to 24-inch zone. In these tests the moisture

on fallow in the 0- to 24-inch zone was 16.2% and on the sudan cover plots 16.4%.

DEPTH AND METHOD OF PLANTING

At each date of planting, blue grama, side-oats grama, buffalo grass, western wheatgrass, and a mixture of these species were drilled with a double-disk grass drill at depths of ½ inch and 1 inch. Broadcast plantings were made at each date of planting with the same species. All plantings, whether drilled or broadcast, were packed with round-bottomed packer wheels attached to the drill. Spring plantings in 1940 and 1941 were made in three kinds of prepared sorghum cover, in Russian thistles, and on fallow. Fall plantings in 1939 and 1940 were made in barley stubble (Fig. 2), millet stubble, Russian thistles (Fig. 1), and on fallow.

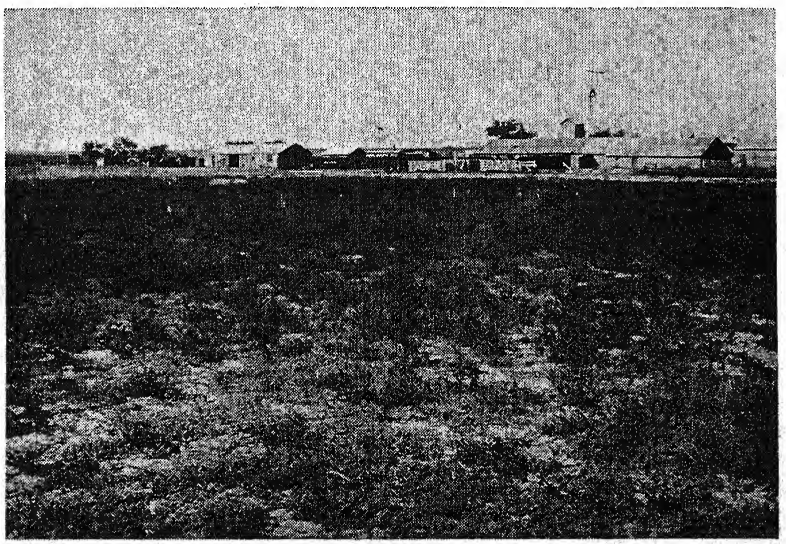


Fig. 1.—Russian thistle weed cover used for grass plantings. From 3 to 6 inches of the top soil on this area had been removed by wind erosion. Photographed September 27, 1940.

These tests showed that regardless of cover type, when moisture conditions were favorable, as in the late summer of 1941, best results were from plantings made ½ inch deep or less. With less favorable moisture, such as occurred during the springs of 1940 and 1941, best results with western wheatgrass were from seed planted 1 inch deep. Blue grama and the grass mixtures predominantly blue grama gave best results when planted ½ inch deep. Under the same conditions, results with side-oats grama varied, depending on the type of cover. In all cases, where the grass mixture was drilled ½ inch deep, the short grasses, blue grama and buffalo grass, were co-dominant with western wheatgrass and side-oats grama in the resulting turf. All

1-inch deep plantings of the grass mixture were ultimately dominated by wheatgrass.

WEED MOWING

Weeds were kept mowed on one of each pair of plots planted to grass during the period covered by these tests for the purpose of determining whether or not weed mowing would increase the rate of establishment of perennial grasses sufficiently to offset the increased cost. Plantings made in the fall of 1939 and spring of 1940 were mowed for weed control three times during the summer and early fall of 1940 and once in the summer of 1941. The plantings made in the fall of 1940 and spring of 1941 were mowed once in July, 1941. These plots, as a whole, were characterized by low to medium height Russian thistles, but a few plots were dominated by pigweed, *Amaranthus retroflexus* L., and witch grass, *Panicum capillare* L.

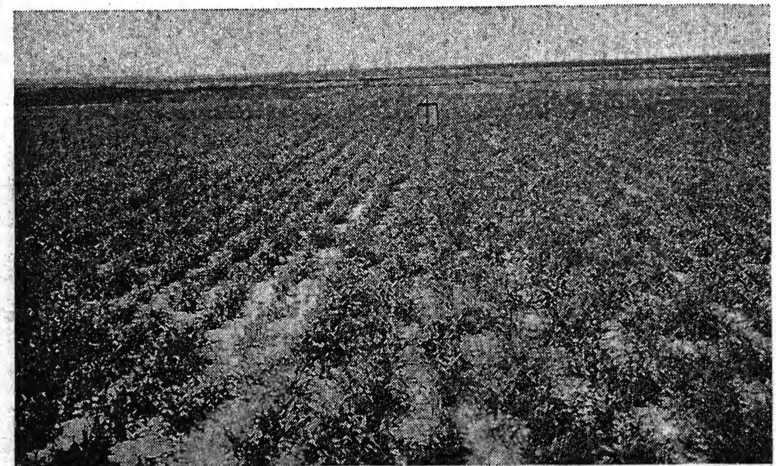


FIG. 2.—Barley stubble and volunteer barley used as a fall planting cover for grass plantings. With favorable late summer moisture, grass seedlings emergence and survival was very good. Photographed September 16, 1940.

At the end of June, 1942, observations and measurements were taken on all plots which had successful grass stands. A total of 240 plots were considered to have successful stands, and of these, 120 had been kept mowed for weed control. The results of the mowing tests indicated several trends. Mowing was unfavorable to wheatgrass in 1941 because this practice reduced the grass volume to less than that on unmowed plots without significantly improving the grass stand. Stands of side-oats grama were improved by mowing in 9 out of 24 plots and in the grass mixture plantings in 3 out of 24 plots. In the remaining plots, results were indifferent. Blue grama stands were in no case visibly increased by mowing (Fig. 3). In 9 out of 24 grass mixture tests the proportion of blue grama and buffalo grass was increased in the resultant turf by mowing. Wherever low-

growing Russian thistles were kept mowed, most of the grass plantings were unresponsive (Fig. 4). Out of a total of 48 plots in the experiment which showed indifferent response to mowing, 33 plots or 69% were plantings in low-growing Russian thistles.

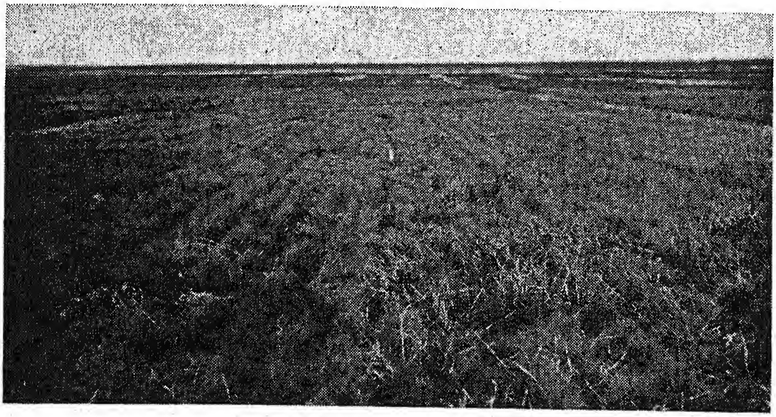


FIG. 3.—Blue grama planted on millet stubble August 23, 1940. Weeds kept mowed on plots to left of white stakes, not mowed on the right. Mowing weeds on pure stand plantings of blue grama did not visibly improve the grass stand. Photographed June 8, 1942.

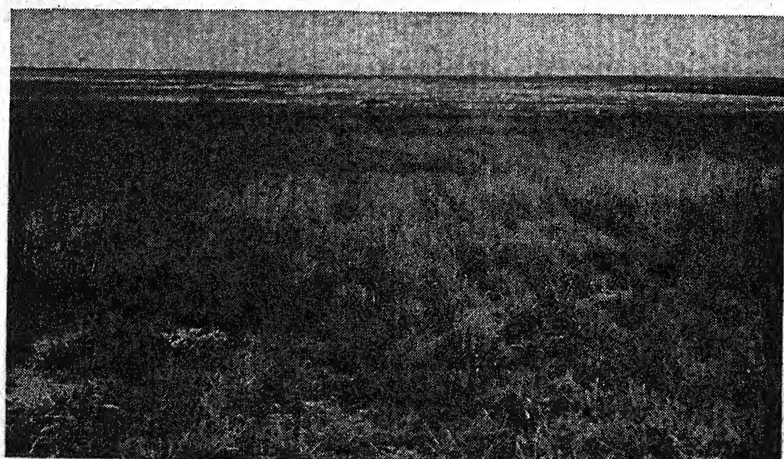


FIG. 4.—Side-oats grama planted in weed cover shown in Fig. 1. Grass planted April 18, 1940. Weed mowing here gave indifferent results. Photographed June 8, 1942.

SUMMARY

Although conditions for grass seedling emergence and establishment in the Great Plains may often be better when seed is planted in non-competitive "prepared" crop residues, the results of this study

indicate that this may not be true under all conditions. As a stabilization practice on large critical areas, there is no question as to the value of "prepared" sorghum covers, but from the results obtained at Cheyenne Wells, it appears that whenever plantings could be made with reasonable safety on clean or fallowed land this method can be expected to produce grass stands in less time than plantings in any kind of "prepared" or weed cover. This is especially true where blue grama is the main species to be planted.

The question may arise as to what constitutes a safe use of fallow in the establishment of grass stands in eastern Colorado. It is certain that under favorable moisture conditions, it should be possible to use fallow in those areas of heavy soils where fallow has been a part of the regular wheat, fallow, wheat or sorghum, fallow, wheat rotations. August grass plantings on land clean fallowed with deep furrow cultivation equipment during May, June, and July, or plantings on land kept fallow by the "stubble-mulch" method, appear to be possible solutions.

Several alternatives are open to the farm operator and farm planner in eastern Colorado for the regrassing of areas now under cultivation. The procedure should differ, depending on the physical characteristics of the land and on how soon a stand of desirable grass is wanted. Progressive, annual retirement and the use of strip cropping, strip reseeding, contour furrows, and terraces over a period of 3 to 5 years would seem to offer certain definite advantages of soil protection, moisture conservation, and probability of success.

There are also several alternative methods for regrassing areas which have a cover of weeds. The method most likely to succeed will depend on the same conditions as for land now in cultivation and in addition on the growth form of the weed cover. From the experience gained in these investigations, it would appear that the chances of direct reseeding are good on heavy soils with a weed cover of low-growing Russian thistles, provided there has been but little soil accumulation from recent dust storms. In any event, it would appear that little is to be gained by tearing out a weed cover to grow a preparatory sorghum or other crop to obtain a "cover" in which to plant. Such a procedure increases the costs and so far no very definite advantages have been seen.

The results of the depth and method of planting tests follow the same trend as those reported by Love and Hanson (7) and by Murphy and Arny (8), i.e., when moisture and temperature are favorable, plantings of ½ inch or less are more successful than deeper plantings. Although depth of planting is often a deciding factor in emergence, it becomes less and less important as time goes on and a stand is established. This is especially true with sod-forming grasses such as western wheatgrass and buffalo grass.

The returns to be expected from the practice of mowing grass plantings is determined by the character of the weeds being mowed, and by the species of grass planted. In eastern Colorado, the mowing of plantings made in certain types of low-growing Russian thistles will not often give significant returns either in increased stands or reduction of weeds. Whenever grass mixture plantings containing

mid-grasses and short grasses are mowed, a co-dominance of short and mid-grasses can be expected in the resulting turf. As a rule, pure stand plantings of blue grama (Fig. 3) and western wheatgrass are not significantly improved by mowing, but buffalo grass can be expected to be improved in almost every case. Mowing of high weeds, such as a rank growth of upright pigweed, *Amaranthus retroflexus* L., in a wet year may be of some value.

It was also found that planting grass seed when moisture conditions were favorable was of greater significance than whether plantings were made in the spring or fall. This was true of the warm temperature grasses, like the gramas and buffalo grass, as well as a cool temperature grass, such as western wheatgrass.

The soil moisture factor of total available moisture in the 0 to 24-inch zone at planting time was found to be of more importance in establishment than any extra moisture possibly conserved during and after seedling emergence, due to the presence of a non-competitive mulch.

LITERATURE CITED

1. CLARK, ORIN RAY. Interception of rainfall by prairie grasses. Ecol. Monographs, 10:243–277. 1938.
2. COLE, JOHN S., and MATHEWS, O. R. Relation of the depth to which the soil is wet at seeding time to the yield of spring wheat on the Great Plains. U.S.D.A. Circ. 563. 1940.
3. CULLEY, MATT. A densimeter, an instrument for measuring the density of ground cover. Ecology, 19:588–590. 1938.
4. DULEY, F. L. Surface factors affecting the rate of intake of water by soils. Soil Sci. Soc. Amer. Proc., 4:60–64. 1940.
5. ————, and KELLY, L. L. Surface condition of soil and time of application as related to intake of water. U.S.D.A. Circ. 608. 1941.
6. ————, and RUSSEL, J. C. Soil and moisture conservation. Jour. Amer. Soc. Agron., 31:703–709. 1939.
7. LOVE, L. D., and HANSON, H. C. Life history and habits of crested wheatgrass. Jour. Agr. Res., 45:371–383. 1932.
8. MURPHY, R. P., and ARNY, A. C. The emergence of grass and legume seedlings planted at different depths in five soil types. Jour. Amer. Soc. Agron., 31:17–28. 1939.
9. SAVAGE, D. A. Grass culture and range improvement in the Central and Southern Great Plains. U.S.D.A. Circ. 491. 1939.
10. ————, and SMITH, JAMES E. Regrassing cultivated lands in the southern Great Plains. The Cattleman, March, 1940:1–8. 1940.

NOTES

WINTER SURVIVAL OF ROUGH- AND SMOOTH-AWNED BARLEYS[1]

IN a previous paper,[2] a relationship between smooth-awnedness and spring habit of growth was shown in segregates from a cross of two barley strains when spring seeded. From fall seeding the rough-awned types produced significantly higher yields than did the smooth-awned types, but no differences were observed in their winter survival. The purpose of this note is to present the results of additional studies on the relationship of awn type and habit of growth.

For these studies a series of six crosses was used, which involved three smooth-awned, three rough-awned, and one hooded strain. The varieties and strains used were Glabron, C. I. 4577; Vaughn, C. I. 1367; Smooth Awn 88, C. I. 7028; Wisconsin Winter, C. I. 2159; Davidson, C. I. 6373; Randolph, C, I. 6372; and Hooded Sel. 1–26; C. I. 7026. On the basis of studies made by Dr. G. A. Wiebe on spring-seeded material at Madison, Wisc., and elsewhere, Glabron and Vaughn are classified as spring types, Randolph as intermediate in habit of growth, and all the others as winter barleys.

The crosses listed in Table 1 were made in the spring of 1939. In 1941 the F_2 plants were classified according to type of awn, the rough- and smooth-awned plants being separated by feeling them. In none of the crosses did the number of rough- and smooth-awned plants differ significantly from a ratio of 3:1; and in the two crosses in which a hooded parent was used, the total population showed the expected segregation of approximately 12 hooded: 3 rough-awned: 1 smooth-awned plant.

That fall (1941) seed was planted from 10 smooth-awned and 30 rough-awned plants chosen at random from each cross. The progenies were classified the following spring. All smooth-awned plants and approximately one-third of the rough-awned plants bred true, confirming the single-factor difference between rough- and smooth-awnedness in each of the crosses.

The true-breeding rough- and smooth-awned lines were bulked by types and planted at Statesville, N. C., in a paired experiment, nine pairs of single 16-foot rows of each cross being planted. The winter of 1942–43 was exceptionally cold and severe injury occurred in the nursery. A difference in type of growth and in hardiness between rough- and smooth-awned types was apparent in most crosses from early in the winter until the last freeze in April, the smooth-awned types having a more erect plant type. The only exception to this was in the cross of Smooth Awn 88 × Randolph. In this cross, notes taken in March show the smooth-awned types to have made slightly more

---

[1]Contribution from the Department of Agronomy, North Carolina Agricultural Experiment Station, Raleigh, N. C. The writers wish to acknowledge the assistance of W. H. Chapman, previously an Assistant Agronomist in this department. Mr. Chapman made the crosses used in this study and assisted with the work through the second generation. Acknowledgment is also due Mr. J. A. Rigney of the Department of Experimental Statistics for his analysis of the data.

[2]MIDDLETON, G. K., and CHAPMAN, W. H. An association of smooth-awnedness and spring growth habit in barley strains. Jour. Amer. Soc. Agron., 33:361–366. 1941.

growth than the rough-awned, but so far as could be observed both had survived the winter equally well. Survival data for all crosses are given in Table 1.

TABLE 1.—*Winter survival of rough- and smooth-awned segregates in six barley crosses, Statesville, N. C., 1942–43.*

Cross	Winter survival, %		
	Rough	Smooth	Difference
Glabron × Davidson	73.8	38.8	35.0
Glabron × Wisconsin Winter	82.8	52.8	30.0
Vaughn × Randolph	84.4	67.2	17.2
Vaughn × Hooded I-26	78.3	65.6	12.7
Glabron × Hooded I-26	76.7	66.7	10.0
Smooth Awn 88 × Randolph	90.0	90.0	0.0

Yield data were also obtained and showed significant differences in each cross in favor of the rough-awned types. Part of the difference was undoubtedly due to the competition and stand differences which resulted from unequal killing in the two types. In fact it may be that nearly all of the yield differences could be attributed to this cause. Correlation studies between differences in yield and differences in survival gave a value for r of .98.

The possibility of other yield factors being associated with those for rough-awn is not overlooked, especially when tests such as these were conducted in early generations. The very close correlation observed between yield and survival of the two types, however, would seem to show that a fairly close relationship exists between rough-awnedness and the winter habit and between smooth-awnedness and spring habit of growth. The linkage is not so close but that winter type smooth-awned strains can be obtained, but in the experience of the writers it makes their isolation from hybrid populations rather difficult.

These studies will be continued, using isogenic lines as suggested by Atkins and Mangelsdorf[3] to determine if there is a direct relationship between type of awn and yield factors. Inheritance studies are also planned which are designed to determine the degree of linkage between the factor for smooth-awnedness and that for spring growth habit.—G. K. MIDDLETON AND R. W. MCMILLEN, *Department of Agronomy, North Carolina Agricultural Experiment Station, Raleigh, N. C.*

[3]ATKINS, I. M., and MANGELSDORF, P. C. The isolation of isogenic lines as a means of measuring the effect of awns and other characters in small grains. Jour. Amer. Soc. Agron., 34:667–668. 1942.

REACTION OF F_1 SORGHUM PLANTS TO MILO DISEASE IN THE GREENHOUSE AND FIELD[1]

BOWMAN, *et al.*,[2] concluded that susceptibility to milo disease is partly dominant and that reaction to the disease is determined by a single major factor difference. A few F_1 plants in the cross Beaver milo × Resistant Dwarf Yellow milo were tested and at first showed considerable resistance to the disease, but their subsequent death sometime later indicated, "that resistance in the F_1 generation was intermediate between the two parents, with a tendency toward a dominance of susceptibility". Since the conclusion regarding dominance was based upon the behavior of only three F_1 hybrid plants, the writers thought it desirable to test larger numbers for the reaction to milo disease.

Male-sterile Western Blackhull plants (resistant to milo disease) were crossed with Darso (susceptible to milo disease) in 1941 and 1942. The F_1 and parent plants were grown in the greenhouse each winter, and in 1943 in the field on infested soil at the Garden City, Kans. Branch Experiment Station.

In 1941 the seed was sown late in November in the greenhouse in flats of soil obtained from Garden City that was infested with the milo disease organism. The plants of the Darso parent were dead by January 1, while those of the Western Blackhull parent and hybrids were still alive, although the hybrid plants did show some injury from the disease. The F_1 hybrids lived about 8 weeks longer than the susceptible parent. Fig. 1 shows a flat containing the F_1 and the parents at the time the F_1 plants were nearly all dead.

In early December, 1942, another planting was made in the greenhouse which gave results similar to those of the previous year, except that the F_1 plants lived longer. Final notes were taken May 7, 1943, and at that time all the F_1 plants were dead except a few which were nearly dead. All plants of the resistant parent were normal in appearance. There were 189 F_1 plants tested in comparison with 107 Darso and 95 Western Blackhull plants. Susceptible Dwarf Yellow milo was planted also in the flats as an additional check and all the plants died early, behaving like Darso.

In 1943, alternate rows of the parents and the F_1 hybrids were planted at Garden City. A total of 367 F_1 plants, 371 Darso (susceptible) plants, and 74 Western Blackhull (resistant) plants were available for study. Fig. 2 shows a row each of Western Blackhull, Darso, and the F_1 taken September 13. At that time no symptoms of milo disease were noted on the above-ground parts of the F_1 population or Western Blackhull plants, while the Darso plants were only about 18 inches tall and nearly dead. Later in the season the F_1 plants showed

---

[1]Joint contribution from the Division of Cereal Crops and Diseases, Bureau of Plant Industry, Soils, and Agricultural Engineering, Agricultural Research Administration, U. S. Dept. of Agriculture, and the Departments of Agronomy and Botany, Kansas Agricultural Experiment Station, Manhattan, Kans. Contribution No. 358 Department of Agronomy and No. 456 Department of Botany.

[2]BOWMAN, D. H., MARTIN, J. H., MELCHERS, L. E., and PARKER, JOHN H. Inheritance of resistance to Pythium root rot in sorghum. Jour. Agr. Res., 55: 105–115. 1937.

the reddening and decay of the roots and in the base of the crown, characteristic of milo disease.[3]

FIG. 1.—Sorghum grown in milo disease infested soil in the greenhouse. Four rows to the left are F_1 plants, row 5 is Western Blackhull, row 6 is Darso, and the three rows to the right are F_1 plants. Photographed about 9 weeks after all the Darso plants were dead.

FIG. 2.—The reaction of F_1 plants and parents to milo disease under field conditions. The row to the left is Western Blackhull (resistant), the center row is Darso (susceptible), and the row on the right is the F_1 which appears resistant at this stage of maturity.

[3]See footnote 2.

The reaction of the F_1 plants was somewhat different in the greenhouse and field plantings. What appears to be a reversal of dominance is merely a shift in expression of disease intensity due to environment. It seems probable that in heavily infested soil and with optimum environmental conditions for early infection in the field, the disease becomes evident early and progresses rapidly until the entire plant is killed, thus showing a behavior similar to that occurring in the greenhouse. When the expression of the disease is less severe in the field, as frequently observed at Garden City, homozygous susceptible plants often reach considerable size and heterozygous plants develop to maturity. In the present studies, although the intensity of the disease differed in the greenhouse and field, it is possible to divide the population into three classes as follows: Susceptible, intermediate, and resistant. The F_1 hybrid plants were classed as intermediate in the greenhouse because they lived considerably longer than the plants of the susceptible parent. In the field, the F_1 plants appeared similar to resistant plants but showed evident injury to the roots and crown of the plant, while there was no apparent injury to the plants of the resistant parent.

These observations show that the reaction of the F_1 hybrid plants varies according to the environment in which they are grown. In the greenhouse under optimum conditions, the expression of the disease in F_1 plants is such that they are killed eventually but live much longer than plants of the susceptible parent. In the field at Garden City, the development of the disease is slower and generally less severe so that the F_1 plants appear normal, but definite symptoms of the disease are found by examining the roots and crown of the plant. If the soil were more heavily infested in Kansas or the environment more nearly optimum for the full expression of the disease, it is believed the symptoms on the leaves and other parts of the plant would become evident in the hybrid F_1 plants.

The male-sterile character has been suggested as a useful method for the commercial production of hybrid sorghum seed.[4] In addition, this character is of value when large numbers of F_1 plants are desired, particularly for pathological and genetic studies, such as those reported here.— E. G. HEYNE, *Division of Cereal Crops and Diseases;* AND L. E. MELCHERS AND A. E. LOWE, *Kansas Agricultural Experiment Station, Manhattan, Kans.*

[4]STEPHENS, J. C. Male sterility in sorghum: Its possible utilization in production of hybrid seed. Jour. Amer. Soc. Agron., 29:690–696. 1937.

A NATIVE GRASS SEEDER[1]

IN THE southern Great Plains, the need to reseed extensive areas of range land to native grasses has been apparent for a number of years. Many areas formerly under cultivation should also be seeded to native grasses. Until recent years, reseeding was left largely to

[1]Contribution from the Amarillo Conservation Experiment Station, Soil Conservation Service, Amarillo, Texas, in cooperation with the Texas Agricultural Experiment Station. Acknowledgment is hereby given to the various technicians in the Soil Conservation Service for suggestions in the development of the broadcast seeder and to H. E. Rea, Texas Agricultural Experiment Station, for assistance in the preparation of this manuscript.

natural agencies. However, during the past 8 years the Soil Conservation Service and other interested agencies have gained considerable experience in this matter and have demonstrated the practicability of making reseedings of native grasses under many conditions. Fig. 1 shows the cover obtained on a badly wind-eroded area in two growing seasons after reseeding with a mixture of native grasses.

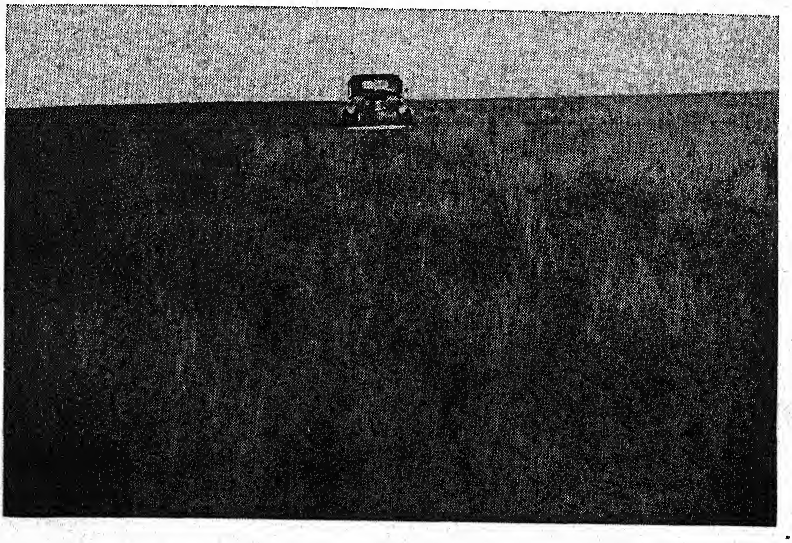


FIG. 1.—A heavy cover of blue grama, side-oats grama, little bluestems, and love-grass and sand dropseed obtained by seeding with a broadcast seeder. This land, which was badly wind-eroded, is now ready for grazing.

When large-scale reseeding of range land was started in 1935, numerous practical problems were encountered. Early trials showed that satisfactory results could not be expected unless mixtures of native grasses were used. Many valuable native grasses have light, fluffy seed that are very chaffy and which could not be distributed satisfactorily with the seeding equipment available. To complicate this problem further, only mixtures of native grasses which contained considerable chaff could be obtained even with the best harvesting methods. Prior to 1935, the design of seeding equipment was almost universally based on the use of clean, free-flowing seed with only a moderate tolerance in seed size to be seeded through a common hopper simultaneously. This situation called for re-designing available seeding equipment to fit the needs of seeding grasses under range conditions.

For sowing clean to moderately chaffy seed on smooth to moderately rough areas, a grass drill, shown in Fig. 2, was developed by several federal agencies from ideas originally used by James E. Smith of the Soil Conservation Service and B. F. Barnes of the Bureau of Plant Industry. For conditions for which it was designed, this drill is very satisfactory. However, it is rather expensive and is poorly suited to

sowing very chaffy seed mixtures and for operations over very rough land. To fit these needs, a broadcast seeder was developed (Fig. 3A). This seeder will operate successfully over extremely rough sand sage brush land and hummocked fields which have been the most difficult areas to plant.

Numerous trials have shown that when seed are distributed with this broadcast seeder and followed by a disk harrow, satisfactory stands of native grasses may be obtained over a wider range of terrain and with chaffier seed mixtures than had previously been practical. Also, the cost of this equipment is very moderate. Grass seed harvested with a grain combine requires no recleaning nor processing before seeding which greatly reduces seed cost. Also, this method makes it practical for a farmer to harvest and plant his own seed.

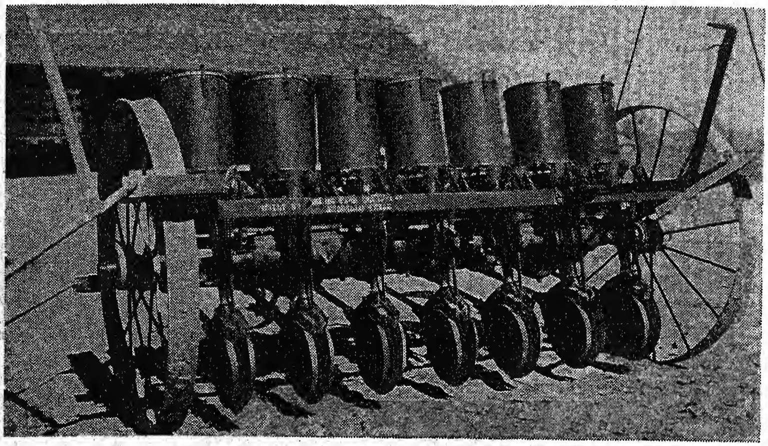


FIG. 2.—Plains grass drill as developed by several federal agencies.

An important feature of this equipment is the variation permitted in number and capacity of hoppers used and in the range in coarseness of their feed outlet. The actual distribution of the seed is by means of a horizontal fan. The size and speed of this fan and the density of the seed used largely determine the distribution spread obtained. With the equipment in Fig. 3A, a spread of from 14 to 20 feet may be obtained with most grass seed. By using a fan of this type, it is practical to feed seed and seed mixtures onto the fan from several hoppers and at varying rates. The capacity of the hoppers used and their feed mechanism may be selected individually to fit the requirements of the seed material to be distributed.

In Fig. 3A, three hoppers are shown; more could have been used. The number of hoppers that may be used need be limited only by the space available on which to mount them and the capacity of the fan. The large barrel hopper and the chassis shown in Fig. 3A are an *adaptation* of a grasshopper poison bait spreader such as is shown in Fig. 3B and which is in common use by farmers in the southern Great

Plains region. The features of the hopper are its size and simplicity of construction and the fact that it may be provided with a feed outlet as coarse as is desired. Several standard endgate seeders also provide some of these features, but in most instances the throats above the outlets of their hoppers are too narrow. Usually, these endgate seeders are not easy to remodel because of their cast iron base.

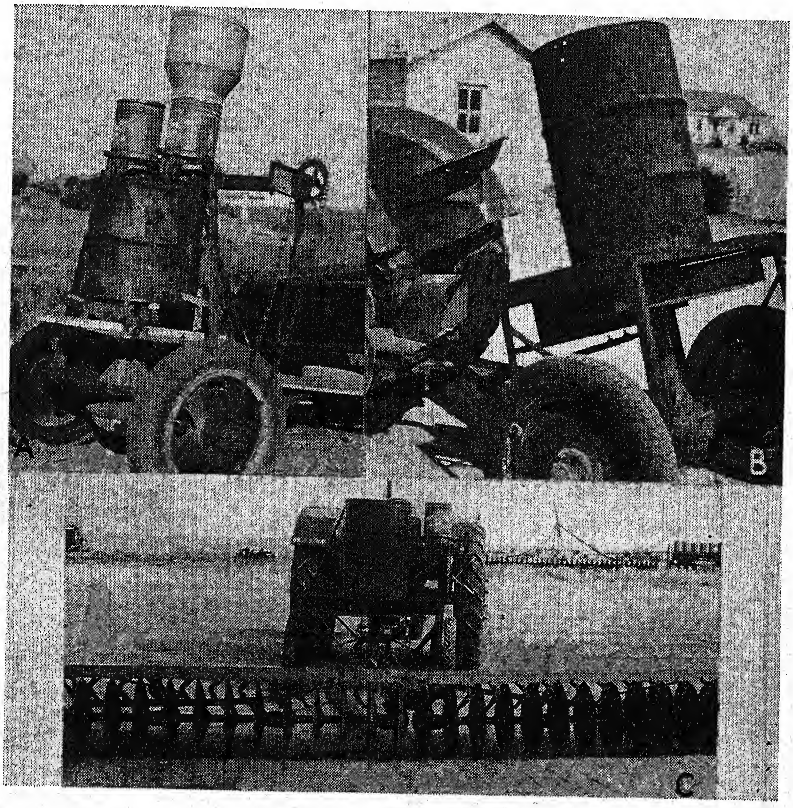


FIG. 3.—A, spreader with two auxiliary planter boxes added, which are powered by a chain drive. These boxes are used for very clean and fine seeds such as sand lovegrass, weeping lovegrass, sand dropseed, and sweet clover, and the barrel for chaffy seed. B, a regular bait spreader adapted for grass seeding. The agitator was lengthened and one additional feed outlet cut in the barrel. C, a seeder developed by J. C. Ebersole, Dalhart, Texas, with one auxiliary box which is a side feed type. This eliminates cutting the barrel down and gives more seed capacity. A 14-foot disk is pulled for covering.

The feed openings in the hopper and the agitator on most poison bait spreaders are satisfactory for seeding grass without changes. Some spreaders have only one feed opening in the hopper and experience has shown that two openings give better seed distribution. Also, the agitator should be longer and wider on some spreaders and, in a few cases, the bottom of the distribution fan is only partially covered,

which is not as desirable as a fan with the complete bottom covered. Fig. 4 shows a detail drawing of the feed openings, agitator, and fan on one of the most successful and easiest constructed spreaders which is ideal for grass seeding. The use of a bait spreader for grass seeding in no way damages it for poison bait spreading.

The two auxiliary hoppers shown in Fig. 3A are standard John

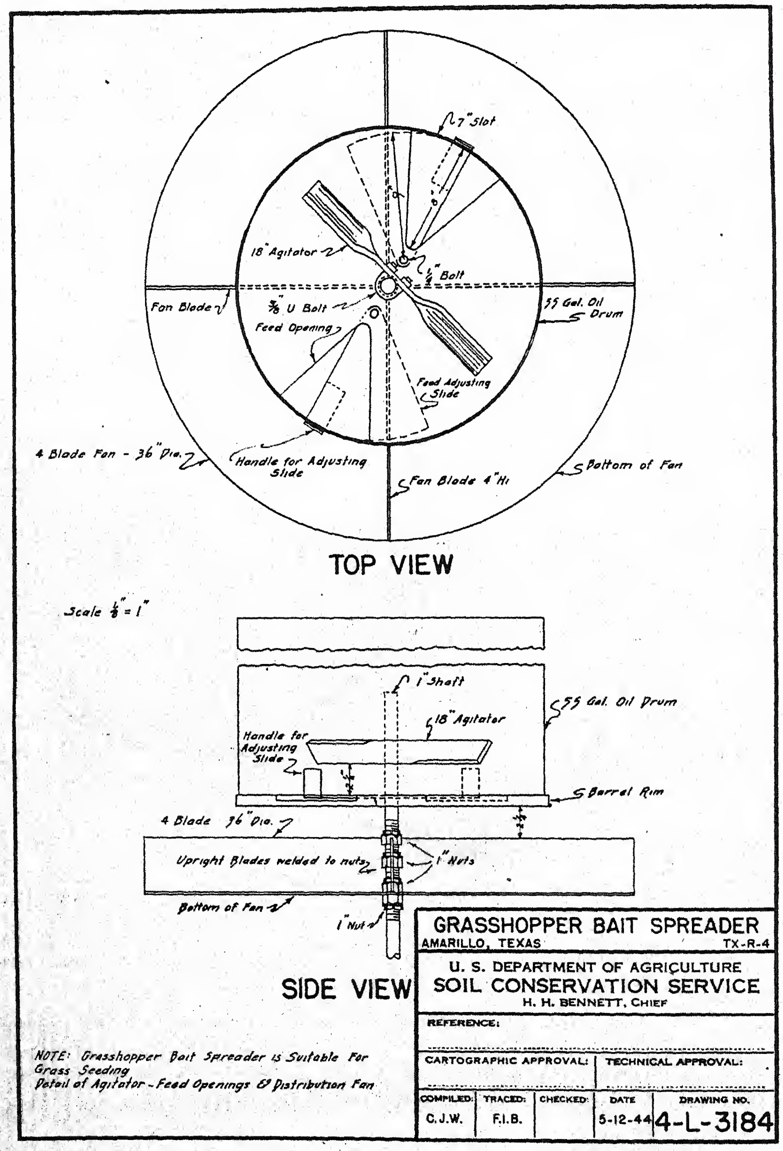


FIG. 4.—Details of the agitator, feed openings, the fan.

Deere cotton and corn hoppers. These hoppers may be provided with a variety of seed and seeding rates. The seed sprouts from these hoppers feed directly to the distributional fan. Also, as shown in Fig. 3A, the capacity of these hoppers may be increased by providing them with extensions.

Fig. 3C shows a disc harrow drawn in tandem with a broadcast seeder. Where the terrain permits, the use of this implement following the seedings insures a more satisfactory stand of grasses.

In making seedings with the equipment shown in Fig. 3A, the various hoppers have been used successfully to handle the seed of the following individual species and mixtures:

1. *Barrel hopper*.—Blue grama, black grama, buffalo grass, side-oats grama, western wheatgrass, Canada wild-rye, little bluestem, sand bluestem, crested wheatgrass, galleta, and needlegrass may be seeded as individual species or any combination of these species in a mixture. Sand dropseed, sand lovegrass, weeping lovegrass and sweet clover may be seeded in the barrel hopper when included in a mixture of such species as blue grama, side-oats grama, or the bluestems which act as "carriers". Grasses similar to the ones listed above could, no doubt, be seeded in this hopper.

2. *Auxiliary hopper No. 1 without can extensions*.—This box is equipped with a sorghum plate and used for seeding fine-seeded grasses and sweet clover. Sand dropseed, sand lovegrass, weeping lovegrass, and sweet clover may be seeded individually or in a mixture. Seeding rate is regulated by using sorghum plates with a varying number of holes.

3. *Auxiliary hopper No. 2 with can extensions*.—This box is equipped with a cotton plate and clean or processed seed of buffalo, blue grama, side-oats grama, western wheatgrass, Canada wild-rye, crested wheatgrass, and little or sand bluestem may be seeded.

By the use of the barrel hopper and one or two auxiliary boxes, it is possible to seed all the common grasses in the southern Great Plains at any desired rate, even though the various species have a wide difference in purity.—HUGH G. PORTERFIELD, *Amarillo Conservation Experiment Station, Soil Conservation Service, Amarillo, Texas*.

AGRONOMIC AFFAIRS

NEWS ITEMS

PROFESSOR WILLIAM ORR WHITCOMB, superintendent of the Montana Grain Inspection Laboratory at Montana State College, Bozeman, died on June 11th. Professor Whitcomb became a member of the Agronomy Department staff on January 1, 1913, and was appointed as superintendent of the Grain Inspection Laboratory in 1920. He had long been a member of the American Society of Agronomy.

—A—

KARL F. MANKE, formerly stationed in Nebraska as a cooperating member of the U. S. Dept. of Agriculture, and more recently, serving as Associate Agronomist with the Texas Experiment Station, has been appointed Assistant Agronomist in corn investigations for the South Dakota Experiment Station at Brookings. He entered upon his new duties on June 15th.

—A—

THE LAMOTTE CHEMICAL PRODUCTS COMPANY of Towson 4, Baltimore, Md., in celebrating its twenty-fifth anniversary, is offering a revised and enlarged edition (84 pages) of its well-known handbook on "The A B C of pH Control". A copy of the handbook may be obtained by writing to the Company.

—A—

THE FRIDEN CALCULATING MACHINE COMPANY, whose general offices and plant are located in San Leandro, California, has recently acquired a building at 336 Madison Avenue, New York City, to house its eastern field management offices. The company is celebrating its tenth anniversary and has issued a 36-page pictorial and factual story of its development and growth. A copy of the booklet may be obtained by writing to the Company at San Leandro, Calif.

—A—

STANLEY F. MORSE, agricultural consultant in private practice for the past 25 years, is heading the American Food Mission which has been sent to French North Africa by the U. S. Foreign Economic Administration. The Food Mission will cooperate with and assist the French Committee of National Liberation in its attempts to restore food production to its pre-war volume in Tunisia, Algeria, and Morocco.

—A—

R. H. MORRISH, formerly Senior Agronomist in the U. S. Dept. of Agriculture, was promoted to the rank of Lieutenant Colonel in the Corps of Engineers on April 3, 1944. Colonel Morrish is stationed in the Office, Chief of Engineers, Washington, D. C., and is in charge of the grounds maintenance, dust, and erosion control work at military installations in the continental United States.

JOURNAL

OF THE

American Society of Agronomy

VOL. 36 AUGUST, 1944 NO. 8

INFLUENCE OF PHOSPHORUS AND POTASSIUM ON SYMBIOTIC NITROGEN FIXATION[1]

JAMES L. ROBERTS AND Frank R. OLSON[2]

IN 1937, it came to the attention of the writers that corn on old experimental plots receiving phosphorus and potassium was often less deficient in nitrogen than corn on plots receiving no fertilizer. A study of the nitrogen content of these plots revealed that fertilized plots usually contained more nitrogen than unfertilized plots in spite of greater removal of nitrogen from fertilized plots by crops. Several greenhouse experiments were then done to determine the extent to which symbiotic nitrogen fixation may be increased by application of phosphorus and potassium to two common soil types and to learn, if possible, something of the role of these elements in the fixation process. Results of these field and greenhouse tests constitute the present report.

The role of phosphorus and potassium in symbiotic nitrogen fixation has not been elucidated, notwithstanding recognition of the fact that leguminous plants grown in field soils usually suffer some degree of deficiency of one or the other of these elements. Studies on these elements are almost entirely confined to their effect on nodulation (2, 4, 11)[3] and protein content (1, 12, 14). Critical biochemical work on symbiotic nitrogen fixation usually has been done on plants grown in complete mineral solutions, where carbohydrate supply or physical factors limit plant growth.

EXPERIMENTAL PROCEDURE

FIELD TESTS

Soil samples from plots on six farms maintained by the Department of Agronomy of the Purdue University Agricultural Experiment Station, were analyzed for total nitrogen content by the Gunning modification of the Kjeldahl procedure. Each plot was 1/20 acre in size. The sample for analysis was a composite of 10 borings to 6-inch depth. Most of the plots studied have been under experi-

[1]Contribution from the Department of Agronomy and Department of Botany and Plant Pathology, Purdue University Agricultural Experiment Station, West Lafayette, Ind. Journal paper No. 147. Received for publication January 24, 1944.

[2]Associate Bacteriologist in Botany and Plant Pathology and Assistant in Agronomy and Botany and Plant Pathology, respectively.

[3]Figures in parenthesis refer to "Literature Cited", p. 644.

mental conditions for approximately 25 years. A system of rotation including a legume is used on all plots. Fertilizers are applied to cereal crops in the rotation and only residual fertilizers from preceding cereal crops are available for the legumes. Detailed description of the plots studied is given in Purdue University Agricultural Experiment Station Circulars 242 to 247, inclusive, by Wiancko and associates.

Estimates of total nitrogen removed from various plots by crops were obtained from yield records, and average percentage nitrogen content of feeds given by Morrison (9). Morrison's figures were used because actual nitrogen analyses for all crops in all years are not available. Analyses of the nitrogen content of crops on certain plots at the Bedford, Lafayette, and North Vernon farms during 1938, 1939, and 1940 by Lucas, Scarseth, and Sieling (7) argee reasonably well with Morrison's figures.

GREENHOUSE TESTS

Unless otherwise noted, Plainfield sand from the unlimed, unfertilized plot at Culver, Ind., was used. This soil is very low in total and available nitrogen. In preliminary tests, the top growth of 10 uninoculated alsike clover plants grown in 200 grams of sterile, unfertilized Plainfield sand contained an average of only 3.2 mg of nitrogen. The top growth of clover receiving complete fertilization contained an average of only 2.8 mg of nitrogen. Since the amount of available nitrogen in the test soils is so small and apparently not influenced by fertilizer treatment, the nitrogen contained in plant tissue, after correction for nitrogen content of seed, is presumed to have been fixed. In each experiment the soil was adjusted to about pH 6.5 with a mixture of 9 parts $CaCo_3$, 3 parts $MgCO_3$, and 1 part $CaSO_4$. Chemically pure KC_1 and $Ca(H_2PO_4)_2.H_2O$ were used as sources of potassium and phosphorus. Soybean seed was inoculated with *Rhizobium japonicum* (Wisconsin strain, 505) and alfalfa and clover seed with proper effective strains of bacteria isolated from plants growing in the field.

Five-inch glazed pots without drain were used as containers. Unless otherwise noted, selected plants were transplanted to these pots at an early stage of growth. The containers were placed on the bench in randomized blocks, usually five in number. The plants of each treatment were composited into a single sample prior to analysis for carbohydrate and nitrogen fractions. Plants were watered daily with distilled water, the amount added being determined by visual observation of soil conditions.

The growth and appearance of plants in the greenhouse generally were quite satisfactory. The lower leaves of soybeans usually showed some yellowing and occasionally dropped from the plant. This condition was not associated with deficiency of phosphorus or potassium. However, the condition was generally confined to three or four of the lower leaves and did not appear seriously to impair the health of the plants. Unless potassium was supplied, soybeans showed striking symptoms of deficiency on Plainfield sand. In each experiment soybeans were harvested after pods were set but before any beans were mature or the plants began to dry.

The total nitrogen content of the plant tissue was determined by the Gunning modification of the Kjeldahl procedure, on oven-dried tissue reduced in a Wiley mill to pass through a 20-mesh screen.

For carbohydrate determinations, the tissue was prepared according to specifications of the American Association of Agricultural Chemists and reducing sugars determined by the method of Stiles, Peterson, and Fred (13) before hydrolysis, after dilute acid hydrolysis, and after hydrolysis with diastase.

Nitrogen fractions were determined as recommended by Orcutt and Wilson (10), including enzymatic hydrolysis.

EXPERIMENTAL RESULTS

FIELD EXPERIMENTS

Nitrogen balance of old fertility plots.—The effect of treatment on the nitrogen economy of the various plots is estimated by adding the number of pounds of nitrogen per acre present when analyses were

made in 1938 to the number of pounds of nitrogen per acre removed by crops, and noting the difference in the resulting sums for any two plots to be compared (Table 1). It will be noted that the estimated difference in the nitrogen content of fertilized and unfertilized plots in some cases is as high as 800 pounds of nitrogen per acre. A difference of this magnitude would indicate a gain in favor of the fertilized plots of about 40 pounds of nitrogen per acre per year. On most farms the bulk of the nitrogen gain is associated with the use of phosphorus, although there is evidence of gain due to potassium on the Huntington, Culver, and North Vernon farms.

TABLE 1.—*Nitrogen balance of variously fertilized experimental plots.*

Soil type and location	Fertilizer treatment	Lbs. soil N per acre[1]	Lbs. N removed by crops[2]	Soil N + N removed	Difference due to treatment
Brookston silt loam, Lafayette[3]	O	2,146	1,358	3,504	——
	Res.	2,260	1,151	3,411	−93
	Res. P	2,246	1,230	3,476	−28
	Res. PK	2,250	1,304	3,554	+51
Bedford silt loam, Bedford[4]	O	1,918	406	2,324	——
	L	1,984	578	2,562	+238
	LP	2,268	944	3,212	+888
"	LPK	2,188	954	3,142	+818
Brookston and Crosby silt loams, Huntington[5]	O	2,860	670	3,530	——
	L	2,000	767	2,767	−763
	L Res	2,820	597	3,417	−113
	L Res P	3,140	733	3,873	+343
	L Res PK	3,500	734	4,034	+504
Plainfield sand, Culver[6]	O	860	236	1,096	——
	L	860	339	1,199	+103
	L	880	379	1,259	+163
	LP	800	390	1,190	+ 94
	LPK	940	440	1,380	+284
Crosby silt loam, Farmland[7]	O	2,940	658	3,598	——
	L	2,940	693	3,633	+ 35
	L	3,000	749	3,749	+147
	LP	3,580	916	4,496	+898
	LPK	3,460	879	4,339	+741
Clermont silt loam, North Vernon[8]	O	1,380	417	1,797	——
	L	1,340	636	1,976	+179
	L	1,340	630	1,970	+173
	L. Res.	1,500	476	1,976	+179
	L Res P	1,460	637	2,097	+300
	L Res PK	1,580	669	2,249	+452
	LP	1,360	813	2,173	+376
	LPK	1,440	887	2,327	+530

[1]Determined in July 1938.
[2]Determined in July 1938. Based on yield records, and average per cent nitrogen content of feeds given by Morrison (9).
[3]Established in 1915.
[4]Established in 1917.
[5]Established in 1919.
[6]Established in 1924.
[7]Established in 1923.
[8]Established in 1921.

Nodulation and nitrogen content of soybeans on the Bedford plots.—In July, 1938, 25 soybean plants and 100 lespedeza plants were carefully removed from each of the plots under investigation on the Bedford farm. Number of nodules and percentage nitrogen content were determined. In the case of soybeans, the dry weight per plant was also measured (Table 2). Yield records (not shown) indicate that considerably more hay and soybeans have been produced on those plots to which fertilizers are applied to corn and wheat in the rotation.

TABLE 2.—*Nodulation and nitrogen content of soybeans and lespedeza from Bedford plots in July, 1938.*

Plot treatment	Nodules per plant	Weight per plant, grams	N, %	Total N per plant, mg
		Soybeans		
O	14	2.34	2.24	52.4
Lime	18	2,74	2.31	63.3
LP	21	4.37	2.37	103.6
LPK	38	5.34	2.46	131.3
		Lespedeza		
O	6.1	—	1.49	—
L	4.8	—	1.55	—
LP	6.5	—	1.98	—
LPK	6.8	—	1.98	—

The results in Table 2 constitute further evidence that legumes have benefited appreciably from the use of fertilizers on corn and wheat. Both number of nodules and percentage nitrogen content of soybeans and lespedeza are higher in the case of plants from fertilized plots.

GREENHOUSE EXPERIMENTS

The influence of phosphorus and potassium on the amount of nitrogen fixed by legumes in two soil types.—Plainfield sand and Clermont silt loam from the unlimed, unfertilized plots at Culver and North Vernon were dried sufficiently to pass through a 2-mm screen, limed, fertilized as desired, and placed in 9-ounce glass tumblers. Two-hundred grams of soil were placed in each tumbler. On June 16, Mandell soybean, alsike clover, and alfalfa seed were inoculated and planted directly into the tumblers. Soybeans were thinned to two plants per tumbler and alsike and alfalfa to ten plants per tumbler. The alfalfa stand in Plainfield sand was very poor and these tumblers were discarded early in the experiment. On August 18, nitrogen was determined on both plant tissue and the soil. The original nitrogen content on the soil and seed was known.

In all cases large increases in growth and in the amount of nitrogen fixed (Table 3) resulted from the use of phosphorus. Alsike clover and alfalfa also responded to potassium if an adequate supply of phosphorus were available. It may be of some interest that soybeans responded similarly to phosphorus in both Clermont silt loam and Plainfield sand, but there was a much greater response of alsike clover in the silt loam than in the sand.

TABLE 3.—*The influence of P and K on nitrogen fixation by legumes, June 16 to August 18.*

Soil treatment, p.p.m.	Mgms of N fixed by legumes in two soil types				
	Soybeans		Alsike		Alfalfa
	Clermont	Plainfield	Clermont	Plainfield	Clermont
None	41	38	16	14	30
P200-KO	69	75	50	25	68
PO-K200	36	47	28	22	49
P200–K200	64	77	93	39	91

Carbohydrate and Soluble nitrogen fractions in variously fertilized soybeans.—Between 1938 and 1941 several experiments were done to determine how phosphorus and potassium influence nodulation by soybeans. Little significant information regarding nodulation was obtained other than that in proper concentration these elements increased the size and number of nodules produced. It was observed, however, that the ratio of carbohydrate to nitrogen, as measured by percentage nitrogen content, was narrower in plants adequately supplied with phosphorus than in plants deficient in phosphorus. Conversely, the ratio of carbohydrate to nitrogen was wider in plants adequately supplied with potassium than in plants deficient in potassium (Table 4). Almost without exception, a deficiency of either phosphate or potassium decreased the absolute amount of nitrogen fixed by soybeans in these experiments.

TABLE 4.—*Percentage nitrogen content of soybeans (all parts) fertilized with phosphorus and potassium.*

Variety	Soil type	Date	Percentage N content of soybeans fertilized as indicated*			
			P_0K_0	P_1K_0	P_0K_1	P_1K_1
Richland	Bedford silt loam	Nov. 1 to Dec. 12	4.27	4.47	3.91	3.80
Manchu	Bedford silt loam	Aug. 25 to Oct. 5	2.63	4.05	1.95	3.24
Mandell	Clermont silt loam	June 16 to Aug. 18	2.85	3.63	2.81	2.96
Mandell	Plainfield sand	June 16 to Aug. 18	2.71	2.95	2.49	3.10
Dunfield	Plainfield sand	Aug. 21 to Oct. 20	2.82	3.32	2.68	2.94
Mandell	Plainfield sand	Nov. 3 to Dec. 15	2.99	3.39	2.82	3.14
Mandell	Plainfield sand	May 30 to July 20	2.66	2.51	2.34	2.47

*The amount of fertilizer used is expressed in arbitrary units, since amounts differed somewhat in different experiments.

Following these observations, an experiment was done to determine reducing sugars, non-reducing sugars, and starch in tops and roots of variously fertilized soybeans after 4, 6, and 8 weeks' growth. Later, soluble nitrogen fractions were assayed in the roots of a second group of plants after 8 weeks' growth. In both these experiments Mandel

soybeans were grown in Plainfield sand and handled in the manner previously described. Results are shown in Tables 5 and 6.

TABLE 5.—*Carbohydrate fractions in variously fertilized Mandell soybeans in Plainfield sand, planted August 23.*

Fertilizer treatment, p.p.m.*	Mgms of carbohydrate per gram of plant tissue at indicated weeks of growth									Mgms of N in tops and roots†		
	Reducing sugars			Nonreducing sugars			Starch			4 weeks	6 weeks	8 weeks
	4	6	8	4	6	8	4	6	8			
						Tops						
0	0	11.9	16.8	0	0.5	0.7	33	113	87	169	216	251
P_{25}	0	11.7	15.8	0	0.7	2.9	26	116	104	156	217	355
P_{75}	0	12.7	17.5	0	0.7	3.2	26	79	69	178	280	439
K_{25}	9.3	12.6	15.4	0	0.4	0.6	19	121	112	197	199	315
K_{75}	7.7	8.6	12.8	0	0.1	1.3	31	86	95	182	206	274
						Roots						
0	9.3	14.3	16.2	0	6.6	1.4	38	38	58	—	—	—
P_{25}	15.8	16.6	17.3	0	2.8	0.3	38	58	34	—	—	—
P_{75}	23.6	22.1	17.7	0	6.6	0.2	44	57	46	—	—	—
K_{25}	22.3	12.7	13.7	0	6.3	2.5	34	52	59	—	—	—
K_{75}	9.9	15.0	11.4	0	1.2	2.4	34	52	57	—	—	—

*Soil was given basic treatment of lime; P, 25 p.p.m.; and K, 25 p.p.m., before indicated fertilizers were added.
†Eight plants.

TABLE 6.—*Soluble nitrogen fractions in variously fertilized Mandell soybean roots and nodules, April 2 to June 1.*

Nitrogen fractions	Mgms/N per 100 ml of juice of plants treated as indicated*			
	P_0K_0	P_{100}-K_0	P_0-K_{50}	P_{100}-K_{50}
Total	45.4	41.2	59.6	53.3
Amide + NH_4	8.1	7.3	8.3	8.0
Basic amino	3.6	2.6	1.6	5.2
Basic non-amino	5.6	7.0	11.5	9.2
Non-basic amino	15.3	12.6	15.8	18.6
Nitrate	3.7	3.0	3.9	2.3
Other nitrogen	9.1	8.7	18.5	10.0

*P and K expressed in p.p.m.

In most instances differences observed were relatively small and not interpretable with certainty. However, two points of possible significance deserve comment. There is at least some indication that in plants properly supplied with potassium there is less decrease in concentration of starch during the period of most rapid nitrogen fixation (sixth to eighth week of growth). The concentration of total

soluble nitrogen in roots of plants deficient in potassium is lower than in roots of plants supplied with this element, whereas the concentration of total soluble nitrogen in roots of plants deficient in phosphorus is somewhat higher than in plants supplied with phosphorus.

INTERPRETATION AND DISCUSSION OF RESULTS

The ultimate objective of a biochemical study of symbiotic nitrogen fixation is to define precisely how various factors influence the process, and where the influence is exerted in the series of reactions through which protein is synthesized from atmospheric nitrogen. The results of the experiments reported are interpreted and discussed in terms of this objective, although obviously the work done is too narrow in scope to yield more than meagre evidence in some cases.

The relatively high concentration of total soluble nitrogen in plants deficient in phosphate suggests that lack of phosphate inhibits the fixation process by interrupting protein synthesis. As Giöbel (3) has pointed out, an accumulation of the first products of fixation might be expected to inhibit further fixation by reason of the law of mass action. The role of carbohydrates is apparently a subordinate one during phosphate deficiency, since fixation proceeds slowly in spite of a wide carbohydrate-nitrogen ratio. Since the carbohydrate-nitrogen ratio of soybeans deficient in potassium is relatively narrow, widening as potassium is supplied in spite of increased nitrogen fixation, it is suggested that potassium may influence nitrogen fixation indirectly through some role in the synthesis of carbohydrate. Such a role has previously been suggested (6). Although analyses for reducing sugars, non-reducing sugars, and starch do not bear out this assumption, neither do they necessarily refute it. The amount of any particular carbohydrate fraction made available over an interval of time might be significantly influenced by potassium without effecting the concentration of that fraction at any given time. If the carbohydrate supply is the first limiting factor in nitrogen fixation by soybeans deficient in potassium, then the effect of carbohydrate deficiency is apparently first exerted within the nodule, and not later in protein synthesis, since soluble nitrogen fractions are less concentrated in potassium-deficient plants than in plants adequately supplied with potassium.

The field experiments and certain of the greenhouse experiments were included in this report, not because they point to new concepts, but rather to emphasize again the need of fertilizing legumes as well as cereals in the rotation if a favorable nitrogen balance is to be maintained. These results are essentially confirmation of previous reports by Mann (8), Hopkins (5), and others. It is a common practice among farmers in Indiana to apply commercial fertilizers, often containing nitrogen, to corn and wheat, but no fertilizer to legumes. Since this practice, which leaves only residual fertilizers for the legumes, improved the nitrogen economy of most soils tested, it might be expected that a practice of applying non-nitrogenous fertilizers dirctly to legumes would have certain advantages.

SUMMARY

The nitrogen content of several experimental plots studied, on which a rotation including legumes was used, was higher where phosphatic and potassic fertilizers were applied than where no fertilizers were applied, in spite of greater removal of nitrogen by crops from fertilized plots. In some cases the nitrogen gain due to use of phosphorus and potassium was as much as 40 pounds of nitrogen per acre per year.

The use of phosphorus and potassium on corn and wheat at Bedford, Indiana, caused an increase in the number of nodules and percentage nitrogen content of soybeans and lespedeza grown in subsequent years. In greenhouse experiments, fertilization of soybeans, alfalfa, and alsike clover increased nitrogen fixation by as much as 30% in some cases.

Soybeans deficient in phosphorus are relatively lower in percentage nitrogen content and contain a somewhat higher concentration of soluble nitrogen than normal plants, suggesting that a deficiency of phosphorus may inhibit nitrogen fixation by interrupting protein synthesis.

Soybeans deficient in potassium are relatively higher in percentage nitrogen and contain a lower concentration of soluble nitrogen than normal plants. These facts may be explained by assuming potassium to have some role in the synthesis or moblization of carbohydrates.

LITERATURE CITED

1. ANDREWS, W. B. Placement of dolomite, superphosphate, and basic slag for soybeans, Austrian winter peas, and vetch. Jour. Amer. Soc. Agron., 32:337–341. 1940.
2. FELLERS, C. R. The effect of inoculation, fertilizer treatment, and certain minerals on the yield, composition, and nodule formation of soybeans. Soil Sci., 6:81–119. 1918.
3. GIÖBEL, G. The relation of soil nitrogen to nodule development and fixation of nitrogen by certain legumes. N. J. Agr. Exp. Sta. Bul. 436. 1926.
4. HELZ, G. E., and WHITING, A. L. Effects of fertilizer treatment on the formation of nodules on the soybean. Jour. Amer. Soc. Agron., 20:975–981. 1928.
5. HOPKINS, C. G. Alfalfa on Illinois soil. Ill. Agr. Exp. Sta. Bul. 76. 1902.
6. JANSSEN, G., and BARTHOLOMEW, R. P. The influence of the potash concentration in the culture medium on the production of carbohydrate in plants. Jour. Agr. Res., 40:243–261. 1930.
7. LUCAS, R. E., SCARSETH, G. D., and SIELING, D. H. Soil fertility level as it influences plant nutrient composition and consumption. Purdue Univ. Agr. Exp. Sta. Bul. 468. 1942.
8. MANN, T. F. Factors that influence nitrogen fixation in soils. Del. Agr. Exp. Sta. Bul. 167. 1930.
9. MORRISON, F. B. Feeds and Feeding. Ithaca, N. Y.: The Morrison Pub. Co. Ed., 20, 1936.
10. ORCUTT, F. S., and WILSON, P. W. Biochemical methods for the study of nitrogen metabolism in plants. Plant Physiol., 11:713–729. 1936.
11. PERKINS, A. T. The effect of several mineral fertilizers upon the nodulation of Virginia soybeans. Soil Sci., 17:439–447. 1924.
12. ROGERS, T. H., and STURKIE, D. G. Effect of fertilizers and method of their application on nodulation, growth, and nitrogen content of hairy vetch. Jour. Amer. Soc. Agron., 31:141–148. 1939.

13. STILES, H. R., PETERSON, W. H., and FRED, E. B. A rapid method for the determination of sugar in bacterial cultures. Jour. Bact., 12:428–435. 1926.

14. VANDECAVEYE, S. C., and BOND, L. V. Yield and composition of alfalfa as affected by various fertilizers and soil types. Jour. Amer. Soc. Agron., 28:491–505. 1936.

SOIL GRANULATION AND PERCOLATION RATE AS RELATED TO CROPS AND MANURING[1]

WM. A. ALBRECHT AND JACOB SOSNE[2]

THE resistance of a soil to erosion and to breakdown of its granulation may be considered a function of the stability of this structure.

A soil is commonly considered to be of less stable granulation and aggregation when it will break down readily under the influence of water. Such soil will flow together and puddle to become more or less impervious. The smaller granules may swell and interstices be filled by individual soil particles, thus sealing the soil to passage of both air and water. As a result, the runoff is increased, thereby increasing erosion. On the other hand, soils whose aggregates are stable enough to hold up under the action of rainfall permit its infiltration. Such soils are well aerated, have good drainage, and store water in significant amounts. Erosion is consequently reduced because of the reduction in runoff. The productivity of such soils is also higher.

There are many factors modifying the stability of granulation, the nature of the cementing materials, and the forces holding the particles together into the granular masses. It was the intent of this study to learn whether the stability of granulation was different in consequence of different crops and of the annual applications of barnyard manure.

PLAN AND PROCEDURE

The soils studied were taken from four plots of Sanborn Field at the Missouri Agricultural Experiment Station. One pair had been in wheat continuously and the other two plots in corn, all since 1888. One of each pair has had no manure treatment. The other has had 6 tons of manure applied annually. All the produce was removed from the plots. The plots are in close proximity and were handled alike so far as possible in all other respects.

Soil samples were taken as borings of the surface 7 inches, spread out indoors, and air dried. The samples were in approximately optimum moisture when taken and in a good state of granulation. The test of the stability of granulation consisted in a measure of the rate of infiltration and percolation of water through a constant volume of soil under a constant head of water.

For this test a volume of 160 cc of air-dry soil was tamped into a 2-inch brass cylinder with a tamping machine. The bottom of the cylinder was perforated and permitted collecting the percolate. Water was run into the cylinder above the soil and a constant depth maintained by means of over-flow. At regular time intervals of 3 minutes after introduction of the water, the amount of percolate was measured by taking 10 measurements, or for a total time of 30 minutes. Replicate measurements were made of the different samples and the duplications were so similar that the data are assembled as graphs in Fig. 1.

RESULTS

It is significant that the infiltration rate was much higher for the soil of both plots under the wheat crop than for the corresponding plots under corn, as shown by the percolation of the water through

[1]Contribution from the Department of Soils, Missouri Agricultural Experiment Station, Columbia, Mo. Journal Series No. 937. Received for publication February 19, 1944.

[2]Professor of Soils and Student Assistant in Civil Engineering, respectively.

the soil of the wheat plots in the short interval of 3 minutes. For the soil under the corn crop with manure there was no percolation until 6 minutes, and for that with no manure there was none until 18 minutes had passed.

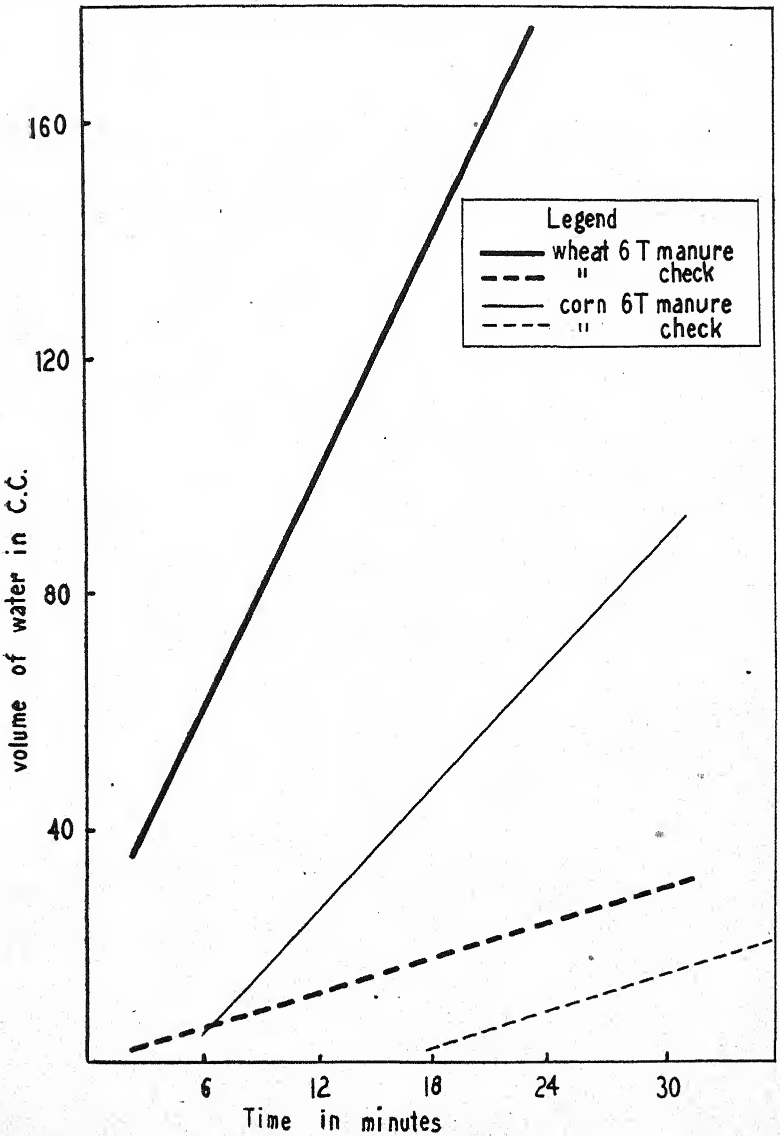


FIG. 1.—Time required for, and rate of, percolation through a soil under different crops with and without manure for 55 years.

The rate of percolation, regardless of the crop, was higher in consequence of the addition of manure. This beneficial effect of the manure was greater when coupled with the effects of the wheat than with those of the corn crop.

The time length under percolation study was not extended far enough to demonstrate much change in rate with increased time of percolation, except to provide a suggestion of a significant decrease in rate after 30 minutes for the soil without manure under wheat.

DISCUSSION

Why these two pairs of plots should be so widely different in stability of granulation of the soils is not readily explainable from their general appearances. These plots are managed differently only in the application of the manure on the surface for the wheat and plowing it under for the corn. There is also the extra surface cultivation for the corn crop.

The extra tillage might be taken as a factor in reducing the organic matter in the soil under corn through hastened decay by more aeration. Under wheat there are greater root additions and more intimate distribution of this organic matter in the immediate surface soil. Even though none of these soils is of a dark color, a visual examination would lead one to believe the manured soil under corn to be higher in organic matter than the manured soil under wheat.

The colors of the soil do not rank them in the order of their stability of granulation as measured by these tests, but their nitrogen contents do. In decreasing rates of infiltration, the plots arrange themselves in the following order: (a) Wheat, manured; (b) corn, manured; (c) wheat, unmanured; and (d) corn, unmanured. The decreasing nitrogen contents of the soils, and therefore their organic matter contents, arrange themselves in the same order according to the following figures as percentages: (a) 0.145, (b) 0.118, (c) 0.098, and (d) 0.071. This agreement emphasizes the fact that for these treatments the rate of infiltration of water into the soil varies with the organic matter content as measured by the nitrogen contents.

SUMMARY

Soils under continuous corn and wheat crops, both with and without manure for 55 years in Sanborn Field, were subjected to study of water infiltration and percolation in the laboratory. The results as reported point with particular emphasis to the effects by manure as organic matter. It encouraged a granulation that permitted increased infiltration. There was a greater stability of the granules as suggested by the nearly constant rate at which water percolated through a shallow soil layer for a limited time in contrast to its decreasing rate of percolation with time for the unmanured soils.

These results point to the less commonly recognized differences within the soils themselves that will modify their behavior in relation to rainfall and running water. They point particularly to the value of organic matter turned into the soil as it may be responsible for these differences, not readily recognizable by casual observation.

HYBRID ALFALFA[1]

H. M. Tysdal and T. A. Kiesselbach[2]

MAXIMUM productivity in alfalfa is obtained in the first-generation hybrid progeny of a cross between two genotypes with high combining ability. The phenomenon of hybrid vigor is thereby most effectively utilized. Through the use of highly self-sterile, cross-fertile parental clones of alfalfa, the resultant seed may rather closely approach a pure F_1 hybrid constitution. Such a single-cross may be used directly for commercial plantings or the seed of two single-crosses thus obtained may be planted under isolation in alternating rows or as a mixture to produce the commercial double-cross alfalfa seed. Double-cross seed produced in this manner will contain some selfed and some sibbed seed, but these will be in the minority. With these qualifications and limitations understood, the progeny is appropriately known as hybrid alfalfa in distinction to the synthetic variety which may be developed by a similar breeding procedure but whose seed is definitely synthesized in advanced generations for use in commercial plantings. The cooperative breeding program at the Nebraska Agricultural Experiment Station has both the F_1 hybrid and the synthetic variety as objectives, but it is believed that the former has the greater possibilities. The use of hybrid vigor may find its expression in the form of either single or double crosses.

The perfection and testing of parental stocks may require several years before release, but the needed basic information is at hand and foundation stocks and hybrid combinations are under test. Improvement in yield of seed, yield and quality of forage, and resistance to certain diseases and insect pests seems assured. It is the chief purpose of this paper to report the underlying information and to describe the procedure of alfalfa improvement by the method of *controlled hybridization* involving known high-combining ability of the component genotypes.

MODE OF REPRODUCTION

As naturally constituted, alfalfa is normally a cross-fertilized crop, although self-fertilization may also occur except where limited by self-sterility. As an average for three Nebraska tests during 1936 to 1939, 89% of the seed resulted from cross-fertilization (9).[3] Knowles (6) reports 94.2% crossing in Canada, and Burkart (2) found 84.5%

---

[1]Contribution from the Division of Forage Crops and Diseases, Bureau of Plant Industry, Soils, and Agricultural Engineering, Agricultural Research Administration, U. S. Dept. of Agriculture, and the Department of Agronomy, Nebraska Agricultural Experiment Station, Lincoln, Nebr., cooperating. Published with the approval of the Director of the Nebraska Agricultural Experiment Station as Journal Series Paper No. 350. Received for publication March 2, 1944.

[2]Senior Agronomist, Division of Forage Crops and Diseases Bureau of Plant Industry, Soils, and Agricultural Engineering, Agricultural Research Administration, U. S. Dept. of Agriculture, and Agronomist, Department of Agronomy, Nebraska Agricultural Experiment Station, respectively.

[3]Figures in parenthesis refer to "Literature Cited", p. 666.

crossing in Argentina. Profitable commercial alfalfa seed production is dependent upon tripping of the flowers by insects. Tripping by insects normally results in pollination of the stigma by a mixture of self-, sib-, and foreign-pollen, with differential fertilization greatly in favor of the latter (3). Seed yields may be expected to vary heritably and with the environment, variations of which influence the physiology of the plant, and with the prevalence of both beneficial and harmful insects.

EVIDENCE OF HYBRID VIGOR

It has already been reported (9) that hand-pollinated crosses between inbred lines have shown, in many cases, considerable hybrid vigor, apparently depending on the combining ability of the parents. The hybrids previously reported were single crosses and yielded from 60 to 139% of the average of the three checks, Grimm, Hardistan, and Ladak, compared in the same nursery. The average of the 28 hybrids under test was 96% of the average yield of the checks. Upon inbreeding, the forage yield of alfalfa is reduced an average of approximately 32% in the first selfed generation, based on results with 54 S_1 lines, with additional decreases in the following selfed generations until a level of about 26 to 30% of the original yield remains at the seventh and eighth generations. A similar, but somewhat more drastic, reduction in seed yield is experienced upon inbreeding. Great differences occur in the amount of reduction between individual lines. There is no doubt, however, that on the average alfalfa exhibits reduction in vigor on inbreeding and hybrid vigor upon crossing.

Additional forage yield tests of 31 different F_1 hybrids bear out the same general conclusions. These 31 hybrids, field tested in 1942 from transplantings made in 1941, were single-crosses whose pedigree involved up to nine inbred lines. The latter were made by crossing a four-line hybrid with a five-line hybrid. The chief value of this test was to find that some of the hybrids produced by crossing two hybrids exhibited as much vigor as the single crosses from inbred lines.

The top five hybrids in order of yield were built up from three, four, two, five, and eight lines, respectively. The average yield of these five hybrids exceeded that of the highest yielding commercial variety in the test by 23%. The average yield of the 31 hybrids was about the same as the average yield of the three standard varieties, Ladak, Hardistan, and Grimm also included in the test.

SIGNIFICANCE OF COMBINING ABILITY

Evidence is accumulating in a number of crops as to the differences in combining ability of various lines to such an extent that it seems unnecessary to draw further attention to this important factor. Nevertheless, in many cases, it has been given so little attention in forage crop breeding that it would seem of interest to present some additional data obtained with alfalfa.

In 1940 and 1941, crosses were made between a number of relatively self-sterile clones. These crosses were made by hand, but without emasculation. Evidence had indicated that, on the average, over 90% crossing could be expected without emasculation (9). The seed of these

F_1 hybrids was planted in the greenhouse and the plants transplanted to the field in the spring of 1942. They were allowed to grow throughout the summer of 1942, yields being taken (two cuttings) in 1943. Lack of seed made it impossible to replicate the plantings of hybrids in the field, and therefore, the variability of the yield data is undoubtedly high and the differences are greater than would be expected in solid plantings. The field itself, however, was relatively uniform and the trend in the results should be significant.

The yields reported as grams per plant, green weight, are given in Table 1. There is a decided difference in combining ability as shown most strikingly by the productivity of the four crosses which have the male parent No. 1015 as compared with the four crosses with the same female parents, but with the male parent No. 1020. The average production in the first case is 1,003 grams per plant, while in the second it is 483 grams per plant. The averages of the other hybrids are intermediate between the two. It is noteworthy that all of the individual hybrids with No. 1015 as the male parent are superior to any of those with No. 1020 as the male parent. Evidently, No. 1015 has high combining ability with the four female plants, whereas No. 1020 does not combine well with any of them. If these plants were selected merely on the basis of their individual superiority, plant No. 1020 would probably be selected as well as No. 1015. It is to be expected that under natural crossing conditions No. 1020 would show the same poor combining ability. Similarly, an open-pollinated variety consists of a mixture of good and poor hybrids resulting in an average yield. On the other hand, if only good combiners were subjected to intercrossing, it is to be expected that the resulting hybrids would be above average in yield.

TABLE 1.—*Forage yields in grams of green weight per plant in space-planted, unreplicated nursery rows of single crosses, showing the effects of combining ability between lines, 1943.*

Male parent	Female parent				Average
	1018	1019	1096	1097	
1015	781	1,186	1,246	800	1,003
1020	520	501	519	390	483
1087	700	940	816	561	754
1094	525	828	830	453	659
Average.....	632	864	853	551	725

SELF-STERILITY, A DESIRED CHARACTER

A consideration of self-fertility relationships in alfalfa breeding is of paramount importance. The question finally resolves itself into whether the plant breeder should select highly self-fertile or highly self-sterile plants, or plants intermediate in self-fertility. From the evidence accumulated to date, the answer is, select highly self-sterile plants. The results of a series of experiments upon which this conclusion is based are given below.

OCCURRENCE OF SELF-STERILITY

The self-fertility of several hundred open-pollinated plants in the breeding nursery was determined by bagging several racemes in the bud stage, allowing the flowers to open and then tripping them without contamination by foreign pollen. The percentage of flowers forming pods under such conditions is taken as the percentage of self-fertility. Studies have indicated that the number of seeds set per flower treated is a better indication of the self-fertility of the plant, because it has been found that the lower the percentage of flowers which set pods the fewer the seeds per pod, thus accentuating the fertility (or sterility) reading. Stating it another way, the more self-fertile the plant, the more seeds per pod when self-fertilized. For practical purposes, however, the percentage of flowers forming pods gives a reliable indication of the self-fertility of the plants and it requires much less labor, because as soon as the counts of developing pods are made (and this can often be done 10 to 14 days after tripping) the tags and pods can be discarded, whereas, if seed counts are made, they must be carried through the season and carefully harvested, threshed, and counted. The percentage of flowers setting pods even with a highly self-fertile plant may vary considerably, depending upon the environment.

A total of 573 alfalfa plants were classified in this manner. The distribution followed closely a normal frequency curve. The average self-fertility of these plants was 45.6%. These determinations were made under good seed-setting conditions in the breeding nursery at the Western Irrigation Sub-station at Scottsbluff, Nebr. When more than 75% of the flowers set pods, it is an unusually high seed set in alfalfa and several plants set over 95%. The self-fertility of plants selfed one to four generations was also determined for 124 plants under similar conditions. These had an average self-fertility rating of 19.5%. The distribution of the percentage of plants in classes of 10% intervals within both open-pollinated varieties and selfed lines is shown in Table 2. In the open-pollinated plants 12.6% of the population was found to be between 0 and 20% self-fertile. Among the selfed

TABLE 2.—*Distribution of alfalfa plants with respect to self-fertility in open-pollinated and self-fertilized populations.*

Percentage self-fertility	Percentage of plants in each fertility class	
	Open-pollinated population (573 plants)	Self-fertilized population (123 plants)
0–10	3.5	36.6
11–20	9.1	23.6
21–30	12.9	13.8
31–40	15.5	15.4
41–50	18.0	4.9
51–60	16.8	3.3
61–70	10.8	1.6
71–80	7.5	0.8
81–90	4.5	0.0
91–100	1.4	0.0

plants, 60.2% had less than 20% self-fertility. This is a point often observed in selfing programs, namely, that it becomes more and more difficult to secure sufficient selfed seed of many lines evidently because of greater self-sterility, though in some cases selfed lines segregate out which are more self-fertile than the parent. No attempt was made to differentiate between the number of generations selfed and the percentage of self-fertility. The low percentage of plants of open-pollinated origin having low self-fertility emphasizes the need for large numbers in a breeding and selection program.

COMPATABILITY STUDIES

Investigations of fertility relationships in many forage and other crops, such as tobacco, have resulted in the development of a rather complete genetic explanation for self- and cross-sterility in many of them. This has been called the "personate" oppositional multiple factor hypothesis. Attention was called to this phenomenon as early as 1915 by East (5), and even earlier by Hildebrand and others. Williams (11) has reported investigations on red clover which explains the self-sterility in that crop. Similarly, Atwood (1) has found the same type of incompatability factors in *Trifolium repens*.

The behavior of alfalfa is similar in many respects to that reported in these crops, but the studies made by Dean (4) indicate that the compatability relationships are not nearly so well defined. It is not a question of complete self-sterility, on the one hand, and complete self-fertility, on the other, but there is a gradation from one to the other, depending upon the plants. Similarly, cross incompatabilities are very rare, though evidence was found by Dean (4) that there are differences in reciprocal cross compatabilities. The entire question of compatability in alfalfa is undoubtedly complicated by the polyploid nature of the plant and the compatability relationships have not yet been clarified. Common alfalfa, *Medicago sativa*, is unquestionably a tetraploid. It appears to exhibit both allotetraploid and autotetraploid characteristics. Studies are underway to determine this point, but in any event, its tetraploid characteristics should be considered in developing a breeding program.

That there can be no doubt of difference in cross compatabilities is illustrated by investigations of sib-fertility carried out on five different F_1 hybrids, each made by hand-crossing two hybrid alfalfa plants. The results are reported in Table 3. In this investigation 5 to 15 F_1 sister plants grown from hand-pollinated seed were tested for self-fertility, sib-fertility, and outcross-fertility. A relatively large number of flowers were used in each case. The self-fertility determinations were made in the usual way, but the number of seeds produced was also determined. At the same time that the flowers were tripped for the self-fertility determinations, other flowers were both self- and sib-pollinated by tripping onto a toothpick laden with pollen from sister plants of the same hybrid. In all cases pollen from only one sister plant was used at a time so that in the detailed results the reciprocal crosses between sister plants could be identified. To report these data, however, would require a good many pages, so only the averages are given in Table 3 under the column headed "self and sib." The polli-

nations with mixed self, sib, and foreign pollen (Table 3, column headed "self, sib, and foreign") were made by tripping the flowers onto a toothpick laden with a mixture of pollen from both a sister plant and from an unrelated yellow-flowered plant. This may also be called a "tester cross" because the pollen parent was chosen in such a way that, if the foreign pollen was the effective agent in fertilizing, it could be determined by observing the flower color of the progeny. The progeny test has not yet been completed. All three types of crosses were made on a given plant at the same time so that the resulting seed pods and seed produced would be comparable within any given set. The production of seed between different hybrids, however, may or may not be comparable.

TABLE 3.—*Seed production of hybrids when pollinated by self pollen, self and sib pollen, and self, sib, and foreign unrelated pollen, as indicated by percentage of flowers forming pods and by number of seed per 10 flowers pollinated.*

Hybrid	Source of pollen*									Increased seed production due to foreign pollen, %†
	Self			Self and sib			Self, sib, and foreign			
	Total number of flowers pollinated	Tripped flowers forming pods, %	Number of seeds per 10 flowers	Total number of flowers pollinated	Tripped flowers forming pods, %	Number of seeds per 10 flowers	Total number of flowers pollinated	Tripped flowers forming pods, %	Number of seeds per 10 flowers	
17-970	335	16	0.9	732	56	10.1	429	65	16.0	+58
07-758	418	22	1.7	1,546	40	6.3	955	48	10.2	+62
17-981	437	20	2.8	1,983	53	5.8	1,270	45	7.3	+26
17-986	390	37	4.7	454	50	7.5	296	46	6.5	−13
17-982	453	29	5.7	780	59	10.3	387	58	9.4	− 9

*The pollen was applied under controlled methods by tripping flowers with a toothpick, which carried the desired pollen in case of crossing. Self pollen is automatically applied in all cases by the tripping procedure.

†Increase due to outcrossing with foreign pollen is determined by comparing the seed production per 10 flowers when both sib and foreign pollen were applied with that when only sib pollen was introduced.

The most interesting comparisons in Table 3 are between the column headed "seeds per 10 flowers" under "self" and the last column of the table. The former gives the average self-fertility of the hybrid, while the latter gives the relative seed production of the flowers which were "sib-pollinated" compared to those to which both sib- and foreign pollen was applied. There is a very good correlation between the self-sterility of the hybrid and increased production resulting from outcrossing. The two most highly self-sterile hybrids show the greatest increase of seed production when out-crossed as compared to sibbed. All hybrids show a greater production when sibbed than when selfed, but the self-sterile hybrids show greater increase when outcrossed as compared to the self-fertile hybrids. The

latter show a slight decrease upon outcrossing compared with sibbing, but this probably represents no significant difference.

Foreign pollen is seen to be more effective in seed production than is sib-pollen when applied to self-sterile hybrid plants. In these tests, pollination by the mixture of sib and foreign pollen resulted in 60% more seed than did sib-pollination alone. It is not yet known what portion of the seed was outcrossed where the flowers were exposed to the dual pollination, though plantings have been made for this determination. Studies (3, 4, 9) have indicated differential fertilization in favor of unrelated pollen. The actual amounts of crossing between plants varying in self-sterility are now being studied.

RELATION OF FORAGE YIELD OF PROGENIES TO SELF-FERTILITY OF PARENTS

A number of experiments have been carried out to determine the practical aspects of selection for either self-fertility or self-sterility. Several years ago 16 outstanding, high seed-producing plants were selected in a relatively poor seed-producing field of Grimm alfalfa (7). The open-pollinated seed from each plant was planted in a yield nursery replicated 18 times, using the field run of seed from the same field as checks. The average yield of cured forage produced by the seed from the selected plants was 2.71 tons per acre compared with 2.94 tons per acre for the field-run seed. This was a statistically significant difference based on a calculated standard error of a difference of 0.08 ton per acre. Many of the progenies from the selected plants were very low in forage yield, resembling a selfed generation, and none of them were superior to the field-run seed. It previously had been found (7) that there is a significant positive correlation (.3781) between self-fertility and seed production under poor seed-setting conditions, but a significant negative correlation (–.3874) between self-fertility and seed production under good seed-setting conditions. The conclusion based on this work was that the high seeding plants under poor seed-setting conditions were more highly self-fertile than the average run of the field so that the seed produced by these plants was the result of self-fertilization in greater degree than the run of the field. Since selfing results in reduced vigor, the progeny of these plants would be low in forage productivity.

In order to study this problem more carefully, 25 open-pollinated plants were selected from the breeding nursery on the basis of their vigor and seed productivity. They were also classified with respect to their self-fertility by the usual test. The open-pollinated seed from each of these plants, which incidentally was produced under good seed-setting conditions in the breeding nursery at the Western Irrigation Sub-station at Scottsbluff, Nebr., was drilled in nursery rows replicated 12 times. The rows were 20 feet long and spaced 18 inches apart. The test was on comparatively uniform soil under irrigation and a very good stand was obtained from all strains, resulting in an unusually good forage test. The nursery was planted in the spring of 1942 and yields were taken both in 1942 and 1943. The results given in Table 4 report the self-fertility and the average yields for 1943. It

is of interest to point out, however, that the 1942 yields, that is the year of seeding, gave precisely the same conclusions that were derived from the results in the second year. The lowest yielding strains in 1942 were the lowest in 1943, and similarly the highest the first year were also the highest the second year. Differences between the groups were in the same direction and had the same statistical significance. This is pointed out in some detail to indicate that considerable reliance can be given to first year yields, providing good stands and good growth are obtained, and if the plots are free from weeds. These plots were weeded by hand the year of planting.

TABLE 4.—*Forage yield (12% moisture) of progeny of open-pollinated plants selected for their general vigor and productivity and subsequently classified according to their self-fertility into the three groups indicated, 1943.**

Highly self-fertile		Medium self-fertile		Highly self-sterile	
Percentage self fertile	Yield, tons per acre†	Percentage self fertile	Yield, tons per acre†	Percentage self fertile	Yield, tons per acre†
91	4.74	48	5.69	30	6.15
93	5.40	51	5.82	26	6.29
83	5.75	50	6.04	29	6.44
80	6.16	50	6.15	18	6.48
89	6.19	51	6.24	18	6.56
84	6.19	49	6.67	27	6.94
83	6.59	50	6.72	15	7.25
80	6.61	57	6.76	—	—
86	6.71	53	7.08	—	—
Av. 85	6.04	51	6.35	23	6.59

*12 replications in 20-foot rows spaced 18 inches apart. Average yield of Ladak, Ranger, Hardistan, and Grimm = 6.61 tons per acre.

†Differences, in tons per acre, required for significance between: (a) The means of any two strains = 0.55 ton (for P = .05); (b) the highly self-fertile and medium self-fertile group means; 0.18 ton (for P = .05); 0.24 ton (P = .01); and (c) the medium self-fertile and highly self-sterile group means, 0.20 ton for (P = .05); 0.26 ton (P = .01).

The plants were divided into three groups for reporting the yields, based on their self-fertility relationships. In the highly self-fertile group, all of the plants were more than 80% self-fertile. In the medium self-fertile group the plants were from 48 to 57% self-fertile, while in the highly self-sterile group all were less than 31% self-fertile. The average yield of the progenies from the highly self-fertile plants was lowest and the progeny from the highly self-sterile plants averaged highest in forage yield. The differences between the means of each of these groups are statistically significant, approaching odds of 100 to 1. Individually, the lowest yielding progenies were found in the self-fertile group and the highest yielding progeny in the self-sterile group. These results show that it is possible to obtain relatively high-yielding progenies from open-pollinated self-fertile plants, but the chances are much better to find superior yielding progenies among the self-sterile plants.

The results of these several tests, all of which agree, suggest that it is preferable to select toward self-sterility in the parent plants. They

also indicate the undesirability of selecting high seed-producing plants under poor seed-setting conditions, unless the plants are known to be of low self-fertility. On the other hand, many of the highly self-sterile plants are among the best seed producers under good seed-setting conditions. It is suggested that the best way to proceed is to determine the degree of self-fertility of the plants themselves. Male sterility, as such, has not been indentified in alfalfa, but its possible occurrence and use should not be ignored.

An additional conclusion may be drawn from this study. The forage and seed yields of the parents were obtained when they were originally selected, and therefore, it can be determined whether the high forage-producing parents gave the high forage-producing progeny. There is apparently very little correlation. The most vigorous parent in the entire lot, weighing 800 grams, had the lowest yielding progeny in the highly self-sterile group. The least vigorous parent in the entire lot, weighing 230 grams, had the highest yielding progeny in the highly self-fertile group. None of the parent plants were from inbred lines. It seems evident, therefore, that plants must be selected not only on the basis of their own performance, but on the basis of their combining ability or prepotency in transmitting the desired qualities to their progenies as well.

FORAGE YIELDS OF HYBRIDS PRODUCED IN NATURAL-CROSSING FIELDS

It is now possible to report alfalfa forage yields of progenies of paired, relatively self-sterile clones producing seed in isolated, field natural-crossing blocks. In 1941, a number of relatively self-sterile plants were selected and increased clonally to plant in isolated blocks in the spring of 1942. An attempt was made to have 10 such clones in all possible combinations and plantings were made to accomplish this, making a total of 45 isolated blocks. Because of rabbit injury and other causes, however, a fairly large number did not produce seed even though the blocks originally contained 200 to 400 spaced plants each. A sufficient number of blocks produced seed, however, to enable planting a forage test in the spring of 1943. The most successful blocks were those planted in isolated city gardens. In addition to the isolated blocks in 1942, each clone was planted, together with the rest of the clones, in a polycross nursery. This was for the purpose of obtaining seed for a test of the progeny of each clone from seed produced under open-pollination conditions.

The seed of the hybrids and polycrosses was planted in a lattice square designed with 49 entries and eight replications in a rather uniform field under irrigation. The plots consisted of two drilled rows 12 feet long and the rows and plots 1 foot apart. If more seed had been available the plots would have been made somewhat larger. It is believed a two-row plot 20 feet long would be quite satisfactory. In some cases, good stands were not obtained and these crosses are omitted from consideration. Table 5 reports the yields in tons per acre of those entries having comparably good stands in the eight replications. In the first column the lots are listed according to a

numbering system which has been in use many years,[4] and which has been found very satisfactory, particularly for perennial crops where the treatment of the same plant might differ from year to year. The clones are given consecutive accession numbers and are listed in Table 5 as 1029, 1035, etc. The first digit of the prefix (as in 29-1029) indicates the year the seed was harvested, while the second digit indicates the treatment during seed production. For example, in "29" the figure "2" indicated the seed was harvested in 1942, and the "9" indicates that the seed was produced under open-pollination in the polycross nursery. Likewise, "22" indicates the year 1942 and that the seed was produced in an isolated block consisting of two clones and that each was harvested separately. Ten different "treatments" can be set up using numbers 0–9. The identification accession number must be entered in a permanent record book, and the history and identification of the plant or seed carefully recorded.

TABLE 5.—*Comparative leaf-hopper yellowing and forage yield per acre (12% moisture) of standard varieties and of hybrids grown from seed produced in natural crossing blocks, 1943.**

Hybrid or variety	Leaf-hopper yellowing, degree†	Forage yield of 2 cuttings, tons‡
29–1029	5.6	2.47
29–1035	4.8	2.45
29–1038	6.5	2.77
22–1006×1038	5.1	2.25
22–1013×1006	7.4	2.35
22–1013×1038	6.3	2.69
22–1019×1048	6.9	3.04
22–1029×1032	7.0	2.49
22–1029×1035	6.4	2.66
22–1029×1038	3.9	2.28
22–1032×1035	7.4	2.38
22–1035×1029	4.9	2.68
22–1035×1032	5.1	2.39
22–1035×1038	4.8	3.01
21–1038	5.1	2.26
22–1038×1006	6.4	2.31
22–1038×1007	6.8	2.20
22–1038×1035	6.8	2.52
Grimm F.C. 22803	6.9	2.60
Ladak F.C. 22650	7.1	2.58
Ranger (Syn-2)	7.0	2.55
Buffalo	7.1	2.53

*Test made in 12-foot, two-row nursery plots replicated eight times in a lattice square design.
†1 = very little yellowing; 5, medium; and 9, very much.
‡Difference necessary for significance between any two means at the 5% level = 0.30 ton per acre; 1% = 0.39 ton.

The polycross yields of three clones are given at the top of Table 5 and following these are a number of hybrids produced in natural crossing blocks. Clones 1006, 1007, and 1013 are from self-fertilized plants, the remaining clones from open-pollinated or artificially

[4]Developed in cooperation with Dr. L. C. Newell who uses the same general system in grass-breeding work.

produced hybrids. The strain marked 21-1038 was from an isolated block in which only the one clone 1038 was planted.

During the 1943 season, the potato leaf-hopper, *Empoasca fabae*, infested alfalfa plantings more than usual in eastern Nebraska. It was possible to obtain readings on leaf-hopper yellowing in the nursery and these are also reported in Table 5.

One of the first considerations in connection with the yield of these natural crosses is whether they show superior hybrid vigor. It should be borne in mind that there was no previous information regarding the combining ability of the clones entering these combinations. If the previous results in artificial crosses could be taken as a criterion, it would be expected that some of them would show mediocre combining ability, while others might prove somewhat superior to open-pollinated varieties. Judging by the results reported in Table 5, this is exactly what has happened. A few of the hybrids are relatively low in yield compared to the standard varieties, while at least two, 1009 × 1048 and 1035 × 1038, are significantly higher in yield than any standard variety included in the test. Together with these results should be considered the ease of obtaining such characters as resistance to diseases and leaf-hopper yellowing. A few of the hybrids were particularly outstanding in this respect, such as, for example, 1029 × 1038 and also 1035 × 1038. It appears much easier to establish these characters in a hybrid than in an open-pollinated variety. Field determinations on seed productivity of hybrids have not been made, but judging from the uniformly high productions of some of the selected clones, it may be expected that properly selected hybrids will show a greater percentage increase in seed yield than in forage yield over open-pollinated varieties.

One other feature of these yields is the differences in reciprocal crosses. In most cases the yields of reciprocal crosses were quite similar, for example, 1029 × 1035 yielded 2.66 tons, while 1035 × 1029 yielded 2.68 tons per acre. In each case the female is listed first. In the cross 1035 × 1038, however, the reciprocal, 1038 × 1035, was significantly lower in yield. One explanation might be that more selfing occurred in the 1038 clone than in the 1035, resulting in lower vigor when 1038 was used as the female parent. Clone 1038 was 18% self-fertile, while 1035 was only 1% self-fertile, indicating the possibility of more selfing in 1038. It appears that this situation should be checked in planning combinations for possible commercial hybrids. This relation also may differ somewhat under different seed-setting conditions where there are different opportunities for crossing by beneficial insects. It is probable that very little selfing will occur when two cross-compatible, relatively self-sterile clones are planted for natural crossing.

COMPETITION AS A FACTOR IN FORAGE YIELDS

If a percentage of sibbing or selfing occurs in a natural crossing block, it is a question of some importance whether the low-yielding segregates will be proportionately reflected in the yield from the mixture. In order to determine this point, plantings were made in

1942 of various mixtures of two strains differing in productivity. Ladak was chosen as the high-yielding strain and selfed seed of similar viability as the low-yielding strain (mostly one generation of selfing). The selfed seed was mixed with Ladak so as to form a composite of 75% Ladak and 25% selfed seed. Another composite was 50% Ladak and 50% selfed seed. These were compared with Ladak planted alone and selfed seed planted alone. The results of the yields obtained in 1943 are given in Table 6. Two different plantings were made, field 1 being under irrigation and field 2 on up-land. In both cases the selfed line yield was far below that of Ladak. Also, in both cases, the relative yield of the mixture was above that which would be expected on the basis of the mixture.

TABLE 6.—*Comparative yields of forage per acre (12% moisture) when seed of two strains differing in vigor is planted alone and in mixtures of various proportions.*

	Proportion of Ladak and selfed seed			
	Ladak, 100%	Ladak, 75%; selfed line, 25%	Ladak, 50%; selfed line, 50%	Selfed line, 100%
	Yield per acre, tons*			
Field 1†.......	5.50	5.58	5.03	3.73
Field 2.......	2.98	2.59	2.57	1.18
Average....	4.24	4.09	3.80	2.46
	Relative Yields, %			
Actual.......	100	96.5	89.6	58.0
Theoretical...	100	89.5	79.0	58.0

*A difference of 0.76 ton per acre is required for significance between any two means in field 1. The error was not calculated on field 2, with only two replications, but variability is high.
†Field 1 planted June 1942; three cuttings taken in 1943. Field 2 planted August 1942; two cuttings taken in 1943.

As an average of both fields, the mixture containing 25% selfed lines produced 96.5% of the Ladak planting, whereas, theoretically, they should have yielded 89.5% Ladak. The 50–50 mixture averaged 89.6% as much as Ladak, whereas its theoretical yield was 79%. It is apparent, therefore, that the higher yielding plants have benefited through competition with less vigorous and lower yielding plants, resulting in a total production nearer that of the high-yielding component. The degree of this competitive effect might be influenced by seeding rate or other conditions. In fact, in one test in which the 50–50 mixture was planted at twice the normal rate so as to provide more intense competition from the Ladak plants, the reduction in yield was not so great as when planted at the normal rate of 12 pounds per acre. These results give an indication of what might be expected if a percentage of the seed from a natural crossing block results from selfing or sibbing. It would apparently require a relatively high percentage of selfing in order to detract greatly from the hybrid yield.

PROCEDURE FOR ALFALFA IMPROVEMENT BY CONTROLLED HYBRIDIZATION

A well-defined method for the obtaining of desirable parental stocks and for subsequent selection procedure greatly simplifies any breeding program. It tends to give the worker a more specific objective for each step, a definite program for the elimination of less-promising material, and systematizes the entire procedure. To this end a program developed for alfalfa breeding and based on principles found in various studies is outlined here. To be sure, this program may not fit all cases, nor is it considered that improvements cannot be developed. Nevertheless, it has lent clarity to the particular breeding program in which it has been used, and appears to promise greater improvement in the crop than has been possible with mass selection procedures. It is given in some detail, therefore, in the following paragraphs.

DEVELOPMENT OF INBRED LINES NOT AN ESSENTIAL STEP

Much can be said regarding the value of selfing in a breeding program. It has been suggested many times that during a selfing program undesirable characters can be eliminated. It has also been stated that certain characters can be fixed more readily by inbreeding than by any other method, and thus greater homozygosity for desirable characters can be attained. No doubt, these statements are all correct, but in the final analysis probably the chief reason for the need of self-fertilized lines in the corn program, which is the best example of the commercial utilization of hybrid vigor, is to duplicate a given genotype which has been found to have superior characteristics and combining qualities. In a crop such as alfalfa, which is a perennial and where clonal propagation is not difficult, a given genotype can be maintained indefinitely, thus eliminating the need of self-fertilization for its continuance. In addition, elimination of the selfing procedure by-passes several years of inbreeding and makes it possible to select within larger populations with the same expenditure of time.

The desirability of large populations in any improvement program cannot be over-emphasized. Moreover, selection for self-sterility, precludes the possibility of obtaining sufficient selfed seed to carry forward the program successfully, unless a fertility factor can be introduced and removed at will, or some type of sibbing procedure is used, or unless partially self-sterile plants are found to be equally as satisfactory as highly self-sterile plants. Observations to date indicate that it is desirable to select for self-sterility, but complete self-sterility apparently is not essential. Plants selected from selfed lines very often lack vigor and their vegetative propagation becomes more difficult. This was found to be the case among the selfed lines 1006, 1007, and 1013 reported in Table 5. Since high-combining ability has been found between plants that have not been subjected to selfing, selfed lines are not necessary to obtain this required characteristic. The question appears to be whether the desired genotypes can be found among hybrids and open-pollinated varieties without selfing. It is believed that in the majority of cases such individuals can be found

if a sufficiently large population is examined, or if proper hybrid combinations are made. While the main breeding program at the Nebraska Station has come to follow this thesis, the merits of selection within self-fertilized lines are also under investigation.

In some cases, a back-cross procedure is being used in the alfalfa improvement program as a method to obtain desired genotypes. This is largely accomplished through natural crosses between selected clones. Ultimately, it may be found desirable to use selfing for one or two generations to obtain the greatest amount of improvement, particularly with respect to certain characters. Selfed lines, however, do not appear essential as a means of obtaining outstanding improvement in alfalfa. On the other hand, where possible, selfing is used in the program as a tool for determining the genetic constitution of selected plants, such as their segregation and self-fertility relationships.

SELECTION OF PARENTAL STOCKS

Those characters most sought in alfalfa that enters commercial channels may be cataloged as follows: High yield of both seed and forage, fine stems, leafiness, superior seedling vigor, favorable protein and vitamin content, cold endurance, and resistance to heaving and to bacterial wilt, leaf spots, virus, and other diseases and to leafhopper damage and nematodes. Selection for adaptation to unfavorable soil conditions may be possible. Self-sterility and cross-fertility are important characters. Autogamy is to be avoided as self-fertilization reduces the progeny yields.

Sources of breeding material.—Alfalfa seed production is restricted more or less to certain districts whose environmental conditions are relatively favorable for seed yields. The more eastern states are largely dependent upon the mid-western and western states for their seed supply. Therefore, it behooves the commercial alfalfa seed grower of these seed districts to grow types that are suitable locally and in demand in the seed-consuming territory. Thus, the alfalfa breeder must recognize the heritable limitations of the material available for making selections. Desirable selections with respect to specific characters are most readily obtained from varieties or strains that are generally possessed of those characteristics. Segregating hybrid material also may be developed especially to facilitate selections with a greater number of desired characters. The original material is obtained from any source in which it is believed the desired genotypes can be found. For example, in breeding for bacterial wilt resistance such varieties as Ranger, Buffalo, Atlantic, Cossack, and Ladak can be used. Strains developed in previous selection programs but which have not attained the rank of varieties also could be included, and hybrids between resistant plants and highly desirable, susceptible plants should not be overlooked. Often such hybrids can be obtained from natural crosses such as might result in a polycross nursery.

Epidemic nursery.—No variety or source is uniformly possessed of only desirable characters. The main objective, therefore, is to eliminate from further consideration as many undesirable plants as

possible and in such a manner that the greatest number are eliminated with the expenditure of the least amount of labor. Thus, in most cases, the first step would be the elimination of susceptible plants by disease. To accomplish this the original seedlings can be inoculated with the bacterial wilt organism and the plants placed in an epidemic nursery. It is also desirable to eliminate the plants on the basis of other diseases or characters if this is readily possible.

Breeding nursery.—The healthy survivors from the wilt nursery are transplanted into a special breeding nursery where the individual plants are observed for such characters as leaf-hopper resistance, leaf spot resistance, seed productivity, and general desirability. Determinations of self-fertility are also made in this nursery if possible. A high percentage of plants are eliminated on the basis of all these characters.

With the more wilt-resistant varieties approximately 1 plant in 300 proves both highly self-sterile and wilt-resistant. Of these exceptional plants, those that are high in seed and forage production are advanced to the polycross (9) nursery preliminary to testing for combining ability.

TESTING FOR COMBINING ABILITY

Those clonal lines surviving the further rigid selection of the breeding nursery are next to be tested for combining ability as a final selection process to determine which ones merit trial in single-cross combinations for the purpose of predicting the performance of all possible double crosses. The selected lines are all established as clones in an isolated *polycross* nursery in which each one is subject to random pollination with the composite pollen carried to them by insects from the same and other clones in the nursery. It has been the experience that most of the seed so produced is out-crossed. The progenies resulting from these clones that were exposed to outcrossing are known as polycrosses. They correspond in a high degree with the topcrosses in corn and serve the same purpose of testing the lines for combining ability. Eventually, it may be found more desirable to use a tester as a pollen parent by surrounding each clone with plants of this common male parent. During the past year Arizona Common, which is wilt and cold susceptible, was used as a common parent, but results of this test are not yet available.

The seed harvested from these open-pollinated clones is not necessarily all outcrossed but may contain varying amounts of selfed seed. As has been explained earlier, the amount of selfed seed in unselected alfalfa seldom exceeds 10 to 20% and is likely to be far less in these polycrosses since the lines have been selected for self-sterility and high cross-fertility.

To insure more representative outcrossing, randomized replicate plots of each clone are grown in the nursery. Since it is much easier to make a dependable appraisal on a replicated row basis than on a single plant basis, as in the breeding nursery, some of the clones can be eliminated in the polycross nursery on the basis of observation. Seed from the replicate plots of each of the selected clones is mixed for

use in testing the performance of the polycross. Triplicate plots of 50 spaced plants each will ordinarily provide ample seed for thorough progeny testing, depending, however, on production per plant. The polycrosses, i.e., open-pollinated progeny from the clones, are tested in well-replicated, close-drilled, nursery plots (8, 10). Records are kept as to yield and the many vegetative characteristics that are of importance in the commercial hay crop. It would be desirable to have "key" tests in various parts of the country representing conditions where the hybrids might eventually be grown. The clones are classified for combining ability on the basis of the performance of their polycrosses.

The program should include a procedure whereby each promising clone would be maintained indefinitely when the various nurseries are discarded and plowed. This can be accomplished by planting a few plants of each selected clone in a *permanent nursery*, preferably replicated, so that all plants will not be at one location in case of gopher damage, or other disturbances. The spacing of the plants in a permanent nursery should be sufficiently wide so that there would never be confusion in their identification. If the plan of the nursery is kept in a record book, reliance will not have to be placed on stakes which might get lost. A very desirable source of material for each new year or cycle of the epidemic nursery is the polycross nursery when it is composed only of the more desirable clones. If crossing with a susceptible tester is found to be a more accurate test for combining ability, the progeny would be less desirable as a source of new lines. In such a case, open-pollinated seed from the permanent nursery would serve as a source for new material since it would contain all of the desirable clones, and natural crosses between these would furnish new and perhaps better genotypes from which to make selection. At the same time material from outside sources should be added as opportunity permits.

SEED PRODUCTION AND TESTING OF SINGLE AND DOUBLE CROSSES

Those clones with favorable prepotency, as measured through the performance of their polycrosses, are arranged in groups of approximately 10 or more each for the purpose of making all possible single-cross combinations. There are 45 different single crosses from 10 clones combining reciprocals, according to the formula $n = \frac{N \times N-1}{2}$ where n = number of different crosses and N = number of lines. To produce these requires 45 small isolated natural-crossing plots in which individual pairs are planted as alternating clonal rows. The seed produced in each of these crossing plots can be harvested in composite, though it would be advantageous to harvest each clone separately for experimental testing, if facilities permit. Reciprocal crosses are regarded as equal, except insofar as the lines may differ in their degree of self-sterility. The resultant single crosses are tested for performance in well-replicated plots.

Experimental evidence shows that superior single crosses can be produced, but it may be open to question whether it is feasible to

produce sufficient single-cross seed for commercial hay production from clonally propagated parents. This problem would be readily solved by the production of double-cross seed. Such double-cross seed could be produced by inter-planting seed of two self- and sib-sterile single crosses. Sib-sterile single crosses have not been produced nor is it expected that they will be, but evidence indicates that with selective fertilization and oppositional factors operating in the tetraploid condition, it might be possible to approach these specifications. Tests are now under way to determine the exact percentage of hybrid seed which might be expected and the performance of the double-cross seed produced in this manner. The possible use of male sterility should also be investigated. To obtain the double-cross combinations the standard prediction procedure used in corn breeding would be applied to the results from the single-cross tests.

Seed of the highest predicted double crosses is produced and thoroughly tested for performance. The seed of any desired double cross is produced in an isolated crossing field planted either to a mixture of equal quantities of seed of the two single-cross parents or planted with seed of the two parents in alternating rows. The latter procedure enables a more definite determination whether a satisfactory stand of both parents persists. Should there be a differential survival of these, the field should be abandoned for hybrid seed production whenever the stand of either single cross has reduced to such an extent that crossing between them cannot be assured. This problem is less likely to become acute if both single-cross parents have been selected on the basis of self-sterility and high resistance to disease and cold. One or more of the most desirable double crosses may be decided upon for commercial production.

SYNTHETIC VARIETIES

Based on present knowledge, the same identical procedure outlined for the selection of high-combining lines for use in hybrids would be used for the development of superior synthetic varieties. Among various alternatives, either a group of high combining clones would be planted together for natural inter-crossing to produce the seed for a synthetic variety, or else a superior double or multiple hybrid would be used as such in its advanced generations. These would be continued for at least a few generations and possibly so long as their identity is maintained. The original clones would be maintained or increased to form a source of uncontaminated foundation seed.

Seed harvested from fields planted to hybrid alfalfa developed as has been described would produce a natural second-generation hybrid progeny and in later generations may be regarded as a synthetic variety. The productivity of such seed is likely to be equal or superior to that of a good standard variety but will be inferior to the F_1 hybrid seed which must be produced anew for each planting. Presumably, less reduction from close breeding will result if more than four high-combining clones are synthesized.

Since a synthetic variety might segregate for unfavorable characters in advanced generations if such were present in the foundation

material, it would be desirable to test the F_2 generation of a hybrid for at least two generations from the clonal mixture before they are released. A test of the original clonal lines for segregation of undesirable characters would be advantageous.

PROCEDURE OF COMMERCIAL HYBRID SEED PRODUCTION

The commercial production of hybrid alfalfa seed is a comparatively simple undertaking. Four pre-determined clonal lines are involved in the commercial double-cross. They are propagated as cuttings rather than by seed. Two crossing fields are required for producing the two single-cross parental stocks. In each of these fields the two needed clones are space planted, respectively, into alternating cultivated rows to bring about the maximum amount of hybridization. Seed of the two resultant single-crosses is planted in alternating rows in a field to produce the double-cross. The seed crop is harvested in composite and constitutes the commercial hybrid seed. It will consist largely of F_1 hybrid seed, though there will be an admixture of some selfed and sib-pollinated or F_2 seed, the amounts varying with the degrees of self-sterility and sib-incompatability in the single-crosses. Since the single-crosses are the result of crossing heterozygous plants, the loss in vigor would be less than if homozygous lines were originally used.

Producing seed of the single-cross parents from cuttings may be undertaken as a separate and specialized business. Estimating very conservatively, it might require ½ acre of each of the two single-cross parents to plant 1,000 acres to the commercial double-cross seed. The single-cross seed is obtained by the commercial seed grower who either plants the two stocks as a mixture in equal proportions, or separately in alternating drilled rows. The field may be continued for hybrid seed production so long as the stand remains satisfactory.

LITERATURE CITED

1. ATWOOD, S. S. Genetics of cross-incompatibility among self-incompatible plants of *Trifolium repens*. Jour. Amer. Soc. Agron., 32:955–968. 1940.
2. BURKART, A. ————. Herbage Abs., 7:296–297. 1937.
3. COOPER, D. C., and BRINK, R. A. Partial self-incompatibility and the collapse of fertile ovules as factors affecting seed formation in alfalfa. Jour. Agr. Res., 60:453–472. 1940.
4. DEAN, J. G. The self- and cross-incompatibilities in seed production of alfalfa *Medicago* species. Master's Thesis, University of Nebraska (unpublished). 1942.
5. EAST, E. M. The phenomenon of self-sterility. Amer. Naturalist, 49:77–87. 1915.
6. KNOWLES, R. P. The role of insects, weather conditions, and plant character in seed setting of alfalfa. Sci. Agr., 24:29–50. 1943.
7. TYSDAL, H. M. Controlled heterosis as a method of forage crop improvement. Spragg Memorial Lectures on Plant Breeding, Michigan State College. 1942.
8. ———— and KIESSELBACH, T. A. Alfalfa nursery technic. Jour. Amer. Soc. Agron., 31:83–98. 1939.

9. ————, ————, and WESTOVER, H. L. Alfalfa breeding. Nebr. Agr. Exp. Sta. Res. Bul. 124. 1942.

10. WEIHING, R. M., and ROBERTSON, D. W. Forage yields of five varieties of alfalfa grown in nursery rows and field plots. Jour. Amer. Soc. Agron., 33: 2:156–163. 1941.

11. WILLIAMS, R. D. Self and cross-incompatibilities in red clover. Fourth International Grassland Congress. 1937.

CHARACTER, FIELD PERFORMANCE, AND COMMERCIAL PRODUCTION OF WAXY CORN[1]

T. A. KIESSELBACH[2]

WAXY corn in the form of hybrids and an open-pollinated variety has been tested for field performance in Nebraska during the 3 years, 1941–43, in comparison with standard non-waxy hybrids and an open-pollinated variety. The Agronomy Department has produced quantities of the variety known as Nebraska Waxy for use in poultry and hog feeding tests conducted by the Departments of Poultry Husbandry and Animal Husbandry, respectively. This waxy variety has been grown 2 years, under contract, by Nebraska farmers for the experimental industrial use of the National Starch Products Company. It is the chief purpose of this paper to report the outcome of these field-performance tests, although a number of related points of special interest also will be considered.

INDUSTRIAL INTEREST

With the restriction of ocean-shipping facilities caused by the war, an active interest developed in the possible use of the starch from so-called waxy cereals as a replacement for that portion of the imported tapioca (cassava) starch which is in special industrial demand because of its peculiar properties. Prior to current emergency restrictions about 350 million pounds of tapioca starch were imported annually into the United States, largely from the Dutch East Indies. Much of this was sold in direct competition with ordinary cornstarch, but it appears that 50 to 75 million pounds have gone into uses for which it is better suited than cornstarch. The properties which make tapioca and waxy cereal starches superior for certain uses are their lack of tendency to gel in solution, their greater tackiness and adhesive strength, and their greater clarity.

Hixon and Sprague (6)[3] have reported that the results of industrial laboratory tests indicate that waxy cornstarch can be substituted satisfactorily for tapioca in the manufacture of adhesives, gums, paper sizes, and puddings. These findings are confirmed by those of Schopmeyer, Felton, and Ford (13) who also report the comparative analyses of products obtained in the wet milling of waxy and common corn, and present data concerning the characteristics of waxy and non-waxy cornstarch.

[1]Contribution from the Agronomy Department, Nebraska Agricultural Experiment Station, Lincoln, Nebr. Authorized for publication by the Director as Journal Article No. 353 of the Nebraska Agricultural Experiment Station. Acknowledgment for assistance with the out-state tests is made to L. M. Camp for 1941 and 1942, and to J. H. Lonnquist for 1943. W. E. Lyness assisted with growing the seed of Nebraska Waxy for commercial planting and grew the crop for the feeding experiments. G. F. Sprague and N. P. Neal of the Iowa and Wisconsin Agricultural Experiment Stations furnished the seed of Iowax 1 and Wisconsin Double Cross Waxy, respectively. A waxy corn breeding program involving the development of high-combining inbred lines and looking forward to superior hybrid combinations is under way, supported in part by a grant from the National Starch Products Inc. Received for publication March 13, 1944.

[2]Agronomist.

[3]Figures in parenthesis refer to "Literature Cited", p. 681.

C. G. Caldwell[4] of the National Starch Products Company has stated that, "Approximately 6,000 bushels of waxy corn grown in Nebraska in the 1942 season were processed for starch in January, 1943, by this Company. There are definite problems in the milling of waxy maize as compared with ordinary corn, due to the differences in content of starch, oil, and water-soluble materials. The yield of starch obtained from waxy maize was somewhat lower and recovery of protein product was more difficult. Aside from these factors, the waxy maize handled about like ordinary corn in the mill operation. It is believed that these problems can be overcome by certain adjustments and changes in the milling procedure. The quality of starch was good. With the 150,000 pounds of 'waxy' starch on hand, the National Starch Products Company is engaged in its evaluation for various uses. Laboratory tests have indicated that in certain types of modifications and uses waxy maize might be superior to tapioca insofar as clarity, lack of gelling tendency, etc., are involved." An additional 23,000 bushels of Nebraska Waxy was grown in 1943 and shipped for similar use.

H. H. Schopmeyer[5] of the American Maize Products Company has advised that production of waxy corn in Iowa for industrial use amounted to approximately 14,000 bushels in 1942 and 100,000 bushels in 1943.

NUTRITIVE VALUE

Very little information concerning the comparative feed value of waxy and non-waxy corn is to be found in the literature. From a feeding experiment at the Nebraska Agricultural Experiment Station comparing yellow waxy and ordinary yellow corn, Hanson (5) concluded that ,"the response of the pigs fed the waxy corn was fully equal to that of the control group." The waxy corn proved less palatable, however, where the pigs were given free choice.

In the first of several contemplated feeding trials with chicks at the Nebraska Station, Mussehl (12) found that, "the first experiment carried on with 170 chicks in each of two lots indicated a very slight advantage for the waxy type ... It can tentatively be concluded that waxy corn is at least the equivalent of No. 2 yellow dent in rations for growing chicks."

DISTRIBUTION AND INHERITANCE OF WAXY STARCH IN CORN PLANTS

The physical difference in the endosperm of waxy and ordinary "starchy" or non-waxy corn was first reported by Collins (3). He applied the designation "waxy" because of the dull waxy appearance of the grain. Sprague, Brimhall, and Hixon (15) have more recently reported on the inherent difference between the two types of starch. They indicate that two types of molecules constitute most starches. Straight chain molecules which make up the "amylose" fraction of starch stain blue with iodine, and branched molecules, which comprise

[4]From correspondence dated May 5, 1943.
[5]From correspondence dated March 9, 1944.

the "amylopectin" fraction, stain reddish with iodine. The starch of ordinary corn is reported as containing 22% of the straight-chain constituent, while that of waxy corn contains only branched molecules. The term "waxy starch" as opposed to "ordinary starch" or "non-waxy starch" has come to be accepted terminology (6), although with other cereals having this type of starch the designation "glutinous" is in more common use. A fairly dependable separation of waxy and common "starchy" kernels can be made on the basis of appearance alone. For absolute identification, however, Weatherwax's (16) method of staining the exposed endosperms with iodine is used. Under such treatment, the ordinary starch stains blue as against a reddish color for waxy starch.

Demerec (4), Brink and Macgillivray (2), and Longley (11) each established a corresponding differential staining, with iodine, of the pollen grains of the two kinds of corn. Brink (1) found the same staining reactions for the carbohydrates of the embryo sacs. From various studies, Kiesslebach and Petersen (9) concluded, "it appears that the waxy carbohydrate is restricted to haploid or 1x tissue, including pollen, embryo sac, and possibly the tissue developed from the antipodals, and to the 3x tissue of the endosperm. Only ordinary starch has been found in the diploid or 2x tissues which make up the rest of the plant."

The waxy character is controlled by a single recessive gene wx, whereas Wx represents the dominant gene for non-waxy.[6] This was first shown by Collins (3) and Kempton (7). In the second generation of a cross between waxy and non-waxy, a simple Mendelian segregation results approximately in 25% of pure waxy kernels, 25% pure non-waxy kernels, and 50% heterozygous kernels whose progeny will segregate in the same proportion in the following generation. This follows the chance formation of equal numbers of male and female gametes of each kind, and random fertilization. Sprague, *et al.* (15) have shown that the waxy gene is not completely recessive. Nevertheless, homozygous waxy kernels on segregating ears may be detected readily by the iodine test. This is important in the breeding programs under way at several experiment stations.

A significant average deficiency of about 1% in the number of waxy kernels obtained in a segregating population frequently has been ascribed to differential rate of pollen-tube growth in favor of the non-waxy pollen grains. Sprague (14) has accounted for the deficiency by difference in speed of pollen germination and establishment on the silks rather than by differential rate of pollen-tube growth. In addition to various other tests reported in the literature on this question and summarized by Kiesselbach and Petersen (9), the segregation of kernels on 86 self-fertilized ears of the cross Nebraska Waxy × St. Charles White was determined at the Nebraska Agricultural Experiment Station in 1943. As determined by the iodine test, these ears averaged 23.95% waxy kernels compared with the theoretical 25%.

[6]The term non-waxy is used throughout this paper to designate common "starchy" corn.

FURTHER OBSERVATION ON THE PHYSIOLOGIC DIFFERENCE OF WAXY STARCH

A further significant difference in the physiologic functioning associated with the waxy and non-waxy carbohydrate in the development of the corn kernel has been observed. This pertains to the comparative effectiveness of starch formation and retention during the process of translocation from the vegetative parts of the plant to the grain.

In a comparative study in 1943 of the weights of waxy and non-waxy kernels on self-fertilized ears produced by 21 F_1 segregating plants of variety crosses and top crosses, the non-waxy kernels were found to be 3.2% heavier, a highly significant increase. A summary of the data follows:

Kind of kernels	Weight per 100 kernels (moisture-free)	
	Grams	%
Waxy	28.4	100.0
Non-waxy	29.3	103.2
Difference*	0.9	3.2

*Difference is highly significant. The starchy kernels of each of the 21 ears were heavier. When the results for the 21 ears were analyzed statistically as a paired experiment, the non-waxy kernels averaged 0.87 gram per 100 heavier (3.2%) than the waxy, requiring 0.1 gram or 0.35% difference at the 1.0% point for statistical significance.

To reduce the experimental error of this kernel-weight determination, only those kernels were taken where the two kinds occurred in pairs, using the technic previously described (8).

With grain of this origin it would appear that the element of hybrid vigor was eliminated as a factor in comparative kernel weights, and that the difference may be attributed entirely to physiologic effects associated with the waxy gene. In explanation, the hypothesis is offered that the enzymes associated with the non-waxy starch are more effective in laying down elaborated materials in the form of starch. This results in a differential osmotic intake and correspondingly greater moisture-free weight of the non-waxy kernels. Such behavior may account for the 3.16% lower starch and 0.87% higher protein percentage reported (13) for waxy corn.

This determination of relative kernel weights differs from those previously reported, all of which have concerned the immediate effect on kernel weight of intercrossing waxy and non-waxy varieties with pollen mixtures. Collins (3) obtained an increase of 16% in kernel weight of Chinese waxy corn outcrossed by dent corn. In published results of Nebraska data (8), two lots of Chinese waxy corn obtained from Collins and described by him as differing in hetero-

zygosity responded to foreign non-waxy pollen by increases of 9.5 and 5.6% respectively. In tests of this character, it is not possible to ascertain how much of the increased weight is due to change of endosperm type and how much to increased hybrid vigor. All of these tests were made with Chinese corn which had undoubtedly been subjected to very narrow breeding and even selfing. From the data now at hand, any kernel-weight increases of waxy corn above about 3% when outcrossed by non-waxy corn may be attributed primarily to change in hybrid vigor.

Schopmeyer, *et al.* (13) report that waxy cornstarch has approximately a 1.0% higher moisture equilibrium than ordinary cornstarch at various humidities and temperatures.

ORIGIN OF NEBRASKA WAXY

A reasonably productive open-pollinated variety known as Nebraska Waxy was developed at the Nebraska Agricultural Experiment Station from an original cross made in 1922 between the unadapted and unproductive Chinese Waxy obtained from G. N. Collins, and the standard Hogue Yellow Dent variety. Waxy kernels from a number of segregating plants were composited and planted in isolation. This waxy progeny was in turn outcrossed by Reid Yellow Dent and pure waxy kernels were again selected in the second generation for continuation of the waxy strain as an open-pollinated variety. This backcrossing of the waxy segregates to a non-waxy variety was repeated three times. The final waxy variety growing in the field has the appearance of a standard locally adapted variety of field corn, with ears and grain of normal size.

The original waxy corn used in the development of this variety was labelled "closebred" by Collins. It evidently was essentially an inbred line because its kernels increased 9.5% in weight when outcrossed in 1922 (8). Its kernels weighed only 10.9 grams per 100 compared with 25.2 grams for standard Nebraska Reid Yellow Dent. In another planting the Chinese corn yielded 36% as much grain per acre as Reid Yellow Dent. Grown comparatively in 1922, the Reid Yellow Dent was 110 inches tall and tasseled on July 24, whereas the Chinese Waxy plants were 85 inches tall and tasseled August 11. With such a closebred line bringing in half of the inheritance in the first cross, it is probable that three backcrossings have not yet completely restored the degree of hybrid vigor that is normal to most standard open-pollinated varieties. It might be expected that further outcrossing would bring about some increased productivity.

FIELD PERFORMANCE

VARIETIES AND HYBRIDS TESTED

Beginning with the spring of 1941, a study has been under way at the Nebraska Agricultural Experiment Station to determine the comparative field performance of various kinds of waxy corn that might be made readily available for commercial production. These

included an open-pollinated variety, Nebraska Waxy, in 1941, with the addition of the F_1 hybrid Iowax 1 (formerly known as Waxy Iowa 939) and Wisconsin F_1 Double Cross Waxy thereafter. There were also tested in 1943 two top-crosses of Nebraska Waxy by Iowax 1 and Wisconsin Double Cross Waxy, respectively. All of these have been compared with two standard commercial non-waxy hybrids that are grown extensively in Nebraska and elsewhere in the Corn Belt, *viz.*, U. S. 13 and Iowa 939, and with a standard open-pollinated non-waxy variety, Reid Yellow Dent. In 1943, as a matter of technical interest, a comparison was also made of the pure white and pure yellow waxy segregates with the non-waxy segregates of the cross Nebraska Waxy × St. Charles White Dent.

TECHNIC OF THE FIELD TESTS

The tests on the Experiment Station farm at Lincoln have been in four-row plots with border rows discarded at harvest, while two-row plots were used in all other tests.[7] The plots were 10 hills long, planted at a double rate and thinned in the seedling stage to two plants per hill. Five to eight randomized replications were used. This manner of testing in adjacent plots permitted inter-pollination between the waxy and non-waxy corn. This would seem to raise the question whether the yields might be modified in response to the immediate effect of foreign pollen. Bearing on this question, 26 random ears each of Nebraska Waxy and Iowax 1 subject to extensive outcrossing in these test plots with both waxy and non-waxy pollen were analyzed with respect to kernel weight effects. To avoid the experimental error of place effect on the ear, only those kernels were taken where the two kinds occurred in pairs.

Averaging the data for all ears, 32% of the kernels proved outcrossed with non-waxy pollen, and it is likely that the outcrossing with unrelated waxy pollen was of similar degree. The non-waxy outcrossed kernels surpassed the moisture-free weight of the waxy kernels in Iowax 1 by 2.8% and in the Nebraska Waxy by 3.9%.

These differences reflect primarily the effects of change in type of starch, difference due to change in heterosis being largely eliminated by extensive outcrossing of the remaining waxy kernels by unrelated waxy pollen. It was previously shown herein that non-waxy kernels may be expected to weigh about 3% heavier than waxy, due solely to a difference in type of starch. It is deduced therefore that a complete outcrossing of waxy by non-waxy might result in as much as 3% error in the grain yield determination of waxy corn. This is based on the assumption that ordinary starch results in a more complete translocation of elaborated materials from the stalk to the grain. Hetero-

[7]From 6 to 30 entries were included in the tests in which these comparisons were made, but only those of interest in this paper are reported. The differences in yield required for significance as calculated by the "analysis of variance" method are given in the tables for each test. A "combined difference required for significance" is calculated from these for several locations or seasons by the formula $1/N \sqrt{a^2 + b^2 + c^2}$, where a, b, and c are the respective differences required for significance.

zygous non-waxy kernels appear to differ from the waxy in a fairly similar degree as do the homozygous non-waxy, though theoretically they might be expected to weigh slightly less, considering the incomplete recessiveness of waxy as shown by Sprague, *et al.*, (15).

The yield response of waxy corn to outcrossing with non-waxy pollen appears similar, though in far lesser degree, to that demonstarted for sweet corn by Kiesselbach and Leonard (10).

RESULTS

Tests in 1941.—Nebraska Waxy was compared in five localities of the state in 1941 with two standard Corn Belt non-waxy hybrids and a productive local strain of Reid Yellow Dent (Table 1). Nebraska Waxy averaged 31.7 bushels per acre compared with 44.2 bushels for U. S. 13. This is a 28% lower yield, the difference being highly significant statistically.

TABLE 1.—*Comparative yields of Nebraska Waxy corn and two standard hybrids and an open-pollinated variety of non-waxy corn in different regions of Nebraska, 1941.**

Kind of corn	Moisture in ear corn at harvest (average of 5 tests), %	Yield of grain in bushels per acre (15% moisture)						
		Nemaha County	Otoe County	Douglas County	Cass County		Average	
					Test 1	Test 2	Bu.	%
U. S. 13 (F_1 hybrid)	20.6	31.1	11.0	50.7	69.3	59.1	44.2	100
Iowa 939 (F_1 hybrid)	18.4	23.1	9.5	59.1	66.7	53.1	42.3	96
Reid (open-pollinated)	19.6	19.0	10.1	47.9	59.4	49.8	37.2	84
Nebr. Waxy (open-pollinated)	22.6	19.9	6.3	46.0	47.0	39.5	31.7	72
Diff. required for significance (P=0.05)		6.4	4.9	4.2	5.1	6.5	2.5	

*Six replications in each test.

Tests in 1942.—In 1942 three kinds of waxy corn were compared with the same non-waxy variety and two hybrids as in 1941. Tests were made in Lancaster, Pawnee, and Saunders counties, except that Iowax 1 and Wisconsin Double Cross Waxy occurred only in the Saunders County test. Averaging the three tests (Table 2), Nebraska Waxy yielded 47.1 bushels compared with 59 bushels for U. S. 13. This is a 20% lower yield, a highly significant difference.

In Saunders County, Iowax 1 (formerly known as Waxy Iowa 939) yielded 94% as much as Iowa 939 and 83% as much as U. S. 13. Wisconsin Double Cross Waxy yielded 9.0% under Iowa 939. A difference of 9.8% is required for significance in the Saunders County test.

TABLE 2.—*Comparative yields of waxy and non-waxy corn in three regions of Nebraska, 1942.**

Kind of corn	Yield in bushels per acre (15% moisture)				
	Lancaster County	Pawnee County	Saunders County	Average	
				Bushels	%
U. S. 13 (F_1 hybrid)	47.6	59.6	69.1	59.0	100
Iowa 939 (F_1 hybrid)	45.8	54.2	61.4	53.8	91
Reid (open-pollinated)	45.0	42.5	56.8	48.1	82
Nebraska Waxy (open-pollinated)	36.4	45.6	55.2	47.1	80
Iowax 1 (F_1 hybrid)	—	—	57.5	—	—
Wisconsin Double Cross Waxy	—	—	52.9	—	—
Dif. required for significance (P=0.05)	7.2	5.4	6.8	3.8	

*Six replications in each test. The yield of Iowax 1 is based on 25% of the plants in each plot which were permitted to outcross, the others having been sib-pollinated by bagging.

Tests in 1943.—In 1943, Iowax 1 and Nebraska Waxy were again compared in three different counties with Iowa 939 and U. S. 13 (Table 3). As an average, with a yield of 51.6 bushels per acre, Iowax 1 yielded 98% as much as Iowa 939 and 87% as much as U. S. 13.

TABLE 3.—*Comparison of waxy and non-waxy open-pollinated varieties and hybrids tested in three regions of Nebraska, 1943.**

Kind of corn	Percentage moisture in grain when husked				Yield of grain in bushels per acre (15% moisture)				
	Lancaster County†	Cass County	Dixon County	Average	Lancaster County	Cass County	Dixon County	Average	
								Bushels	%
Non-waxy open-pollinated:									
Reid Yellow Dent	16	—	—	—	59.4	—	—	—	—
Non-waxy hybrid:									
U. S. 13	17	17	27	20	72.9	58.4	47.0	59.4	100
Iowa 939	15	16	21	17	62.2	54.3	42.5	53.0	89
Waxy open-pollinated:									
Nebraska Waxy	18	19	29	22	58.8	50.2	32.1	47.0	79
Waxy hybrid:									
Iowax I	15	14	22	17	60.6	51.4	42.7	51.6	87
Waxy top-crosses:									
Nebr. Waxy × Wisc. Waxy Double Cross	15	16	24	18	60.5	46.1	38.2	48.3	81
Nebr. Waxy × Iowax 1	16	19	23	19	58.8	54.4	43.7	51.4	86
Diff. required for significance (P=0.05)					6.1	5.3	9.9	4.3	

*Eight replications in Lancaster County; five elsewhere.
†Moisture in ear corn.

Nebraska Waxy yielded 79% of U. S. 13. A cross between Iowax 1 and Nebraska Waxy yielded within 0.2 bushel of Iowax 1. A cross between Nebraska Waxy and Wisconsin Double Cross Waxy was but slightly superior to Nebraska Waxy. Differences of 7.2% are statistically significant in these comparisons.

In the Lancaster County test on the Experiment Station farm (Table 4 and Fig. 1), Wisconsin Double Cross Waxy and Reid Yellow Dent were also included. The Wisconsin hybrid yielded 1.7 bushels under Nebraska Waxy which in turn yielded only 0.6 bushel less than Reid Yellow Dent, but 14.1 bushels, or 19% less than U. S. 13. In this test differences of 6.1 bushels or 8.3% are statistically significant.

Summary for 3 years.—As an average for the 3 years, involving 11 tests (Table 5), Nebraska Waxy has yielded 23% less than U. S. 13, and 16% less than Iowa 939, a difference of 4% being required for statistical significance.

With a gain in yield of 4% over Nebraska Waxy in 1942 (Table 2) and 10% in 1943 (Table 5), Iowax 1 may be regarded as distinctly superior. It also has more desirable vegetative characteristics and is nearly a week earlier ripening.

Compared with Iowa 939, Iowax 1 yielded 6% less in 1942 and 2% less in 1943. Based on these 2 years' data, requiring a combined difference of 6% for statistical significance, it would seem reasonable to conclude that Iowax 1 may be expected to yield approximately 96% as much as Iowa 939. Vegetative characteristics of the two are rather similar, the waxy type being 1 day earlier ripening.

Compared with U. S. 13, which has consistently proved superior to Iowa 939 in these tests, Iowax 1 yielded 17 % less in 1942 and 13% less in 1943. It therefore appears that Iowax 1 may be rated as about 15% lower yielding than U. S. 13 in regions where the latter is well adapted.

A 4% lower yield of Iowax 1 compared with Iowa 939 may be regarded as some evidence that the waxy character holds down the yield. Bearing on this point, the waxy seed picked from 20 segregating ears of the cross Nebraska Waxy × St. Charles White Dent and tested at the Experiment Station in 1943 (Table 4) yielded 62.2 bushels per acre compared with 63.1 bushels for the non-waxy seed from the same ears. The vegetative characteristics of the progenies from the two kinds of seed as well as the grain yields were similar.[8] Thus there appears to be no linkage of the waxy gene with other important yield factors.

The yield of 62.2 bushels for the waxy segregates from the new cross of Nebraska Waxy by St. Charles White (Table 4) compared with 58.8 bushels for Nebraska Waxy would seem to confirm the opinion expressed earlier (page 672) that the yield of Nebraska Waxy is still depressed as the result of the initial introduction of an inbred line as one parent. As a further determination for these comparable

[8]It should be noted that one-third of the progeny from these non-waxy seeds would theoretically be pure non-waxy, while two-thirds would be heterozygous for the waxy character.

segregates, there was no difference in speed or percentage of emergence after planting, 89% of the waxy and 89.5% of the non-waxy having emerged.

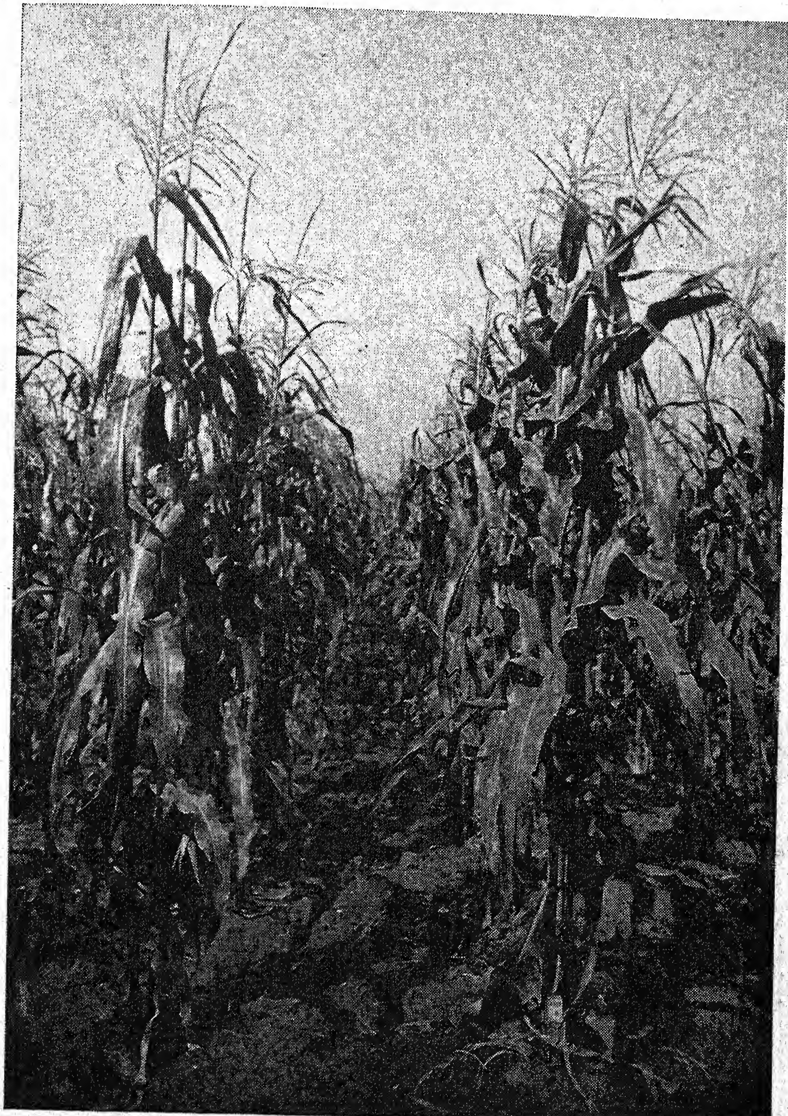


FIG. 1.—Comparative growth of Iowax 1 (left) and Iowa 939 (right) in the yield tests on the Agricultural Experiment Station farm at Lincoln in 1943. Respective mature grain yields were 60.6 bushels and 62.2 bushels per acre. Photographed August 19, approximately 3 weeks before ripe.

TABLE 4.—*Comparison of waxy and non-waxy open-pollinated varieties and hybrids on the Experiment Station Farm, Lincoln, Nebr. 1943.**

Kind of corn	Field stand at harvest, %	Date in tassel, July	Date ripe, Sept.	Number per 100 plants				Height, inches		Moisture in ear-corn when husked, %	Shelled grain		Yield per acre (15% moisture, bu.†
				Suckers	Lodged	Broken	Smutted	Stalk	Ear		%	Test weight, lbs.	
Non-waxy Corn													
Reid (open-pollinated)	96	27	17	19	9	13	9	96	42	16	87	59	59.4
U. S. 13 (F_1 hybrid)	98	30	19	26	3	10	9	100	43	17	87	58	72.9
Iowa 939 (F_1 hybrid)	97	24	13	16	2	6	6	95	40	15	85	57	62.2
Waxy Corn													
Iowax 1 (F_1 hybrid)	99	24	12	12	5	12	3	95	40	15	84	57	60.6
Nebr. Waxy (open-pollinated)	98	29	17	34	9	10	10	96	42	18	86	60	58.8
Wis. Double Cross Waxy (F_1)	100	23	11	8	1	14	4	96	41	14	86	58	57.1
Iowax 1 × Nebr. Waxy (F_1)	99	26	15	22	7	14	10	96	42	16	84	59	58.8
Wis. Double Cross Waxy × Nebr. Waxy (F_1)	100	25	14	21	4	15	6	96	41	15	86	59	60.5
Waxy vs. Non-waxy Segregates from Nebr. Waxy × St. Charles White													
Waxy segregates, white grain	98	28	17	19	6	15	11	11	92	40	21	86	61.7
Waxy segregates, yellow grain	97	28	17	18	6	16	10	10	93	42	21	86	62.6
Av. waxy segregates	98	28	17	19	6	16	11	93	93	41	21	86	62.2
Non-waxy segregates	99	28	17	18	6	17	10	10	94	42	20	86	63.1

*Eight replications.
†Difference required for significance (P = 0.05), 6.1 bushels.

TABLE 5.—*Comparative yields of waxy and non-waxy hybrids and varieties of corn for the 3 years, 1941–43.**

Kind of corn	Yield per acre (15% moisture), bu.				
	1941, av. 5 tests	1942, av. 3 tests	1943, av. 3 tests	Average	
				Bushels	%
U. S. 13 (F_1 hybrid)	44.2	59.0	59.4	54.2	100
Iowa 939 (F_1 hybrid)	42.3	53.8	53.0	49.7	92
Reid (open-pollinated)	37.2	48.1	—	—	—
Nebr. Waxy (open-pollinated)	31.7	47.1	47.0	41.9	77
Iowax 1 (F_1 hybrid)	—	—	51.6	—	—
Dif. required for significance (P=0.05)	2.5	3.8	4.3	2.1	

*Compiled from Tables 1, 2, and 3.

New white and yellow open-pollinated waxy varieties have been established respectively from the white and yellow waxy segregates of the cross between Nebraska Waxy and ordinary St. Charles White. Color proved to be no factor in the yield of the crop. While it is probable that any commercial production in the future will be confined to waxy hybrids, these open-pollinated varieties may serve as a further source for breeding material.

DISCUSSION

If industry finds itself in need of domestically produced starch with characteristics similar to those of the imported cassava starch, waxy corn is available and may serve this purpose very well. Iowax 1 has proved most productive of the various kinds tested in Nebraska. So far as is known these tests included all kinds of waxy corn currently available for commercial production. Iowax 1 appears to yield approximately 4% less than the standard Corn Belt hybrid Iowa 939 with which it is essentially isogenic, except for the waxy factor (15), and 15% less than the popular U. S. 13 under conditions where the latter hybrid is well suited. Other tests have indicated that Iowax 1 and Iowa 939 would more nearly approach the yield of U. S. 13 if their field stands were increased about 20%.

These yield relationships are of decided importance in determining the premium that must be paid the grower of waxy corn as an inducement for its production. Community production of waxy corn would reduce the difficulty of providing the needed isolation from other kinds of corn. Some tolerance as to purity appears permissable. The grower should not be required to take the risk in this matter and the degree of isolation should be specified in the production contract. It has been the common experience in contract production that farmers demand additional payment for arranging their fields to provide special isolation. Aside from these items there need be no additional cost in the growing of waxy over non-waxy corn. There may be a

little hazard under contract production of having one's corn rejected because of not meeting certain specifications, in which case any lower yield would not be offset by an increased price to the grower.

Since the starch of waxy corn has distinctly different properties from that of ordinary corn, the two kinds should not become mixed when sold to the trade. Since only a very limited amount of waxy corn, not to exceed about 3,000,000 bushels per year, is actually needed to meet all special requirements, this situation is best controlled by contract production, requiring delivery of all grain produced, with no reservation on farms for seed purposes. Even with equal yields, there would seem no inducement to grow the waxy type for either the general market or for feed, as no significant superiority for feed purposes has been established. There is satisfaction in the feeding results to-date, however, in that any surplus could be met with no greater loss than that associated with lower yield. Continued waxy corn breeding programs ultimately are likely to reduce this yield differential.

Industry would be warranted in paying a premium for only such amount of waxy starch as is needed for specialized uses in which it serves better than does ordinary starch.

SUMMARY

There is a limited demand for either imported or domestically produced starch possessing the peculiar characteristics of tapioca starch. Under current conditions the starch industry would be warranted in paying a premium, if necessary, for 50 to 75 million pounds of such starch annually, in comparison with the price of ordinary corn starch.

The industry has found certain cereal crops, notably waxy corn and waxy sorghum, to be satisfactory domestic sources for the replacement of tapioca starch made from the imported cassava root. Waxy corn appears to be especially suitable for this purpose because it can be milled with the same equipment already extensively used for ordinary corn.

Field performance tests have been made during 3 years, in eastern Nebraska, of several waxy corns having commercial possibilities in comparison with standard Corn Belt hybrids and an open-pollinated non-waxy variety. Of these, Iowax 1 (formerly known as Waxy Iowa 939) proved most productive and possessed superior vegetative characteristics during the 2 years tested, 1942–43.

As an average, Iowax 1 was found to yield approximately 4% less than Iowa 939 and 15% less than U. S. 13 under prevailing conditions, a difference of 6% being required for statistical significance. It would seem advantageous to have Iowax 1 produced in territory where Iowa 939 is being extensively grown because of its special adaptation. Less price premium would need be paid there by the industry as a special inducement for its production than under conditions where a larger, later-maturing hybrid as U. S. 13 is superior.

Because of the differences in characteristics and utilization of waxy and non-waxy starch, and the very limited specialized demand for

the waxy-type starch, promiscuous production of waxy corn and its admixture with non-waxy corn should be avoided. This is best accomplished through strict contract production.

With a loss of its waxy character when outcrossed, waxy corn fields should be reasonably isolated from other corn, the degree of isolation being specified by the contracting company.

When grown in test plots subject to extensive outcrossing with unrelated pollen of both waxy and non-waxy corn, the outcrossed non-waxy kernels of Nebraska Waxy and Iowax 1 were 3.9 and 2.8% heavier, respectively, than the waxy kernels occurring on the same ears.

No significant difference was found in the yield per acre from white and yellow waxy segregates. Comparable waxy and non-waxy segregates yielded essentially the same, and there was no significant difference in seedling emergence or vegetative habits.

The observation that the waxy character may result in approximately 3% less translocation from the stalk to the grain suggests that two hybrids, identical in all genes except waxy, would differ about 3% in yield of grain per acre. This may account largely for the 4% lower yield of Iowax 1 compared with Iowa 939.

Subjecting waxy corn plants to outcrossing by non-waxy pollen in varietal test plots may result in a maximum error of about 3% in the acre-yield determination, the amount depending upon the proportion of outcrossed kernels.

Further tests of segregating populations confirm the earlier findings as to differential fertilization, there being a deficiency of about 1% in the total expected number of waxy kernels. Instead of 25% of the kernels on selfed segregating ears being homozygous for waxy, only 23.95% were so classified.

LITERATURE CITED

1. Brink, R. A. Mendelian ratios and the gametophyte generation in angiosperms. Genetics, 10:359–394. 1925.
2. ———, and MacGillivray, J. H. Segregation for the waxy character in maize pollen and differential development of the male gametophyte. Amer. Jour. Bot., 11:465–469. 1924.
3. Collins, G. N. A new type of Indian corn from China. U. S. D. A. Bur. Plant Ind. Bul. 161. 1909.
4. Demerec, M. A case of pollen dimorphism in maize. Amer. Jour. Bot., 11:461–464. 1924.
5. Hanson, L. E. Waxy corn vs. non-waxy corn for pigs in dry lot. Nebr. Agr. Exp. Sta. Ann. Rpt., 57. 1944.
6. Hixon, R. M., and Sprague, G. F. Waxy starch of maize and other cereals. Ind. & Eng. Chem., 34:959–962. 1942.
7. Kempton, J. H. Inheritance of waxy endosperm in maize. U. S. D. A. Bul. 754. 1919.
8. Kiesselbach, T. A. The immediate effect of gametic relationship and of parental type upon the kernel weight of corn. Nebr. Agr. Exp. Sta. Res. Bul. 33. 1925.
9. ———, and Petersen, N. F. The segregation of carbohydrates in crosses between waxy and starchy types of maize. Genetics, 11:407–422. 1926.
10. ———, and Leonard, W. H. The effect of pollen source upon the grain yield of corn. Jour. Amer. Soc. Agron., 24:517–523. 1932.

11. LONGLEY, A. E. Chromosomes in maize and maize relatives. Jour. Agr. Res., 28:673–681. 1924.
12. MUSSEHL, F. E. Growth promoting value for chicks of waxy corn. Nebr. Agr. Exp. Sta. Ann. Rpt., 57. 1944.
13. SCHOPMEYER, H. H., FELTON, G. E., and FORD, C. L. Waxy cornstarch as a replacement for tapioca. Ind. & Eng. Chem., 35:1168–1172. 1943.
14. SPRAGUE, G. F. Pollen tube establishment and the deficiency of waxy seeds in certain maize crosses. Nat. Acad. Sci., 19:838–841. 1933.
15. ————, BRIMHALL, B., and HIXON, R. M. Some effects of the waxy gene in corn on properties of the endosperm starch. Amer. Soc. Agron., 35:817–822. 1943.
16. WEATHERWAX, P. A rare carbohydrate in waxy maize. Genetics, 7:568–572. 1922.

CONSTITUENTS OF THE CRUDE CAROTENE OF SOME FORAGES[1]

A. R. KEMMERER, J. F. FUDGE, AND G. S. FRAPS[2]

THE carotene content of Texas range forages has been discussed in a previous paper (4).[3] Recently, it has been found that carotene extracts are more complex mixtures than they were considered to be at that time (1, 2, 3). The crude carotene solutions may contain beta-carotene, impurity A, neo-beta-carotene B, neo-beta-carotene U, and sometimes alpha carotene (3). The neo-beta-carotenes are stereoisomers of beta-carotene and can be formed from, and converted into, beta-carotene (3, 5). Neo-beta-carotene B and alpha-carotene have one-half the vitamin A potency of beta-carotene, while impurity A and neo-beta-carotene U do not appear to possess vitamin A potency (2).

Because of recent discoveries concerning the complexity of crude carotene, it seemed desirable to determine its constituents, as prepared from various forages. It also seemed desirable to discuss the results in terms of beta-carotene equivalent, which is the quantity of beta-carotene, plus one-half the quantity of neo-beta-carotene B, plus one-half the quantity of alpha-carotene, when present. This beta-carotene equivalent is equal to the pigments which have vitamin A potency, expressed in terms of beta-carotene.

EXPERIMENTAL

Range forages were collected during the summer and fall of 1943. Fresh samples were preserved with methanol as previously described (4). Dried grasses were prepared by drying fresh grasses at 65°C for approximately 6 hours. Crude carotene was determined by the A. O. A. C. method for dried hays and grasses. Chromatographic analyses were made by a method already published in detail (2).

In brief it is as follows: Five to 10 grams of fresh material, or up to 20 grams of dormant grasses, were placed in the chamber of a Waring blendor and chopped for 5 minutes at room temperature, with 125 to 150 ml of 12% alcoholic potassium hydroxide. The crude carotene was then extracted with petroleum naphtha (Skellysolve F) and freed from xanthophylls by washing with 90% methanol. The extraction was made without heating, in order to avoid the formation of the stereoisomers of beta-carotene. Methods which employ heat, such as the A. O. A. C. method, may cause the formation of these stereoisomers, especially neo-beta-carotene B (1, 2, 5). The crude carotene extract was concentrated to 10 to 15 ml in vacuo and passed through a column of calcium hydroxide. The calcium hydroxide was washed with petroleum naphtha until the various zones of pigments had separated. If the zones did not separate clearly, the column was washed with a solution of petroleum naphtha, containing 1 to 5% acetone, until they separated. The zones of pigments formed in the column beginning at the top were (a) impurity A, consisting of several small zones; (b) neo-beta-carotene U, an orange zone, just above the beta-carotene zone; (c) beta-carotene, a bright orange zone; (d) neo-beta-carotene B, a light orange zone immediately below the beta-carotene zone; and (e) alpha-carotene, if present, immediately below the neo-beta-carotene B zone.

Calcium hydroxide was used for the chromatographic column because it has been found to be an adsorbent which satisfactorily separates the neo-beta-

[1]Contribution from the Division of Chemistry, Texas Agricultural Experiment Station, College Station, Tex. Received for publication March 13, 1944.

[2]Chemists and Chief of Division of Chemistry, respectively.

[3]Figures in parenthesis refer to "Literature Cited", p. 687.

carotenes (2). Magnesium oxide does not have this property. Previous work (2) also has shown that neither the procedure used in the preparation of the extracts nor the chromatographic technic used caused the formation of either the neo-beta-carotenes or impurity A.

DISCUSSION OF RESULTS

The crude carotene contents on the dry basis and the percentages of constituents of the crude carotene for the fresh green forages are given in Table 1, and for the dried and dormant grasses and silages in Table 2. The percentages of constituents were calculated on the total amount of the several pigments recovered after adsorption on the calcium hydroxide column, as was done in previous work (2). In only a few cases was this total below 90% of the crude carotene. For the purpose of comparison, the average percentages of ingredients were also calculated as though the crude carotene contained no impurity A. Calculation on this basis gives a better idea of the relative quantities of the various carotenes present.

The fresh green forages listed in Table 1 contained from 98 to 400 p.p.m. of crude carotene. Impurity A in the crude carotene ranged from 3.2 to 10.8%, with an average of 6.4%; neo-beta-carotene U from 0.0 to 16.9%, with an average of 12.1%; beta-carotene from 64.2 to 89.1%, with an average of 72.7%; and neo-beta-carotene B from 5.0 to 12.7%, with an average of 8.8%. The beta-carotene equivalent for the 31 samples, excluding bur clover, ranged from 69.6 to 82.6%, with an average of 77.1% and a standard deviation of 2.5%. The beta-carotene equivalents in 29 of the 32 samples were within 5% of the mean. Therefore, for 29 out of 32 of the samples analyzed, the amount of biologically active pigment in units of beta-carotene can be calculated within 5% by multiplying the parts per million of crude carotene by the factor 0.77. This factor can apparently be used for any similar fresh green forages with a reasonable degree of accuracy. Since chromatographic analyses are tedious to run and require an experienced worker, some workers may prefer to determine crude carotene and use the factor for beta-carotene equivalent.

The dried grasses (Table 2), prepared from some of the fresh grasses listed in Table 1, had a crude carotene content which ranged from 75.4 to 128.0 p.p.m. The percentages of impurity A and of the two neo-beta-carotenes in the crude carotene were higher than in the fresh green grasses; beta-carotene was about 10% lower. The beta-carotene equivalent ranged from 65.1 to 70.2%, with a mean of 67.8% and a standard deviation of 1.9%. When impurity A is excluded, the average percentages of the two neo-beta-carotenes are higher in the dried grasses than in the fresh grasses.

Crude carotene in the dormant grasses (Table 2) ranged from 8.0 to 71.6 p.p.m. Impurity A in the crude carotene averaged 25.5%, being much higher than the 6.4% in the fresh or the 11.4% in the dried grasses. Neo-beta-carotene U and B averaged 15.6% and 7.8%, respectively, which are only slightly different from those in the dried grasses. The beta-carotene equivalent ranged from 33.5 to 66.3%, with an average of 55.8% and a standard deviation of 10.0%. Variations in beta-carotene equivalent were much greater among different

TABLE I.—*Carotenoid constituents of crude carotene fractions from fresh grasses.*

Common and botanical names	Crude carotene dry basis, p.p.m.	Percentage of constituents of crude carotene				
		Impurities A	Neo-beta-carotene U	Beta-carotene	Neo-beta-carotene B	Beta-carotene equivalent
Bahia grass, *Paspalum notatum*	399	4.0	15.4	68.0	12.6	74.3
Beard grass, Australian, *Andropogon intermedius*	184	6.1	10.6	76.1	7.2	79.7
Bermuda grass, *Cynodon dactylon*	—	6.4	8.4	80.0	5.2	82.6
Bermuda grass, *Cynodon dactylon*	198	6.1	10.9	73.0	10.0	78.0
Bermuda grass, South African, *Cynodon transvaaliensis*	120	7.6	12.2	71.4	8.8	75.8
Bluestem, big, *Andropogon provincialis*	147	7.6	11.1	73.1	8.2	77.2
Bluestem, South African, *Hyperrhenis hirta*	194	5.3	12.5	76.5	5.7	79.4
Bristle grass, plains, *Setaria macrostachys*	226	6.8	13.5	70.0	9.7	74.9
Buffalo grass, *Buchloe dactyloides*	163	9.3	10.3	74.5	5.9	77.5
Buffalo grass, *Buchloe dactyloides*	210	10.0	15.1	64.2	10.7	69.6
Crab grass, *Digitaria sanguinalis*	305	5.9	11.0	76.0	7.1	79.6
Crab grass, *Digitaria sanguinalis*	244	6.6	12.9	69.3	11.2	74.9
Dallis grass, *Paspalum dilatatum*	267	6.7	10.6	70.0	12.7	76.4
Eastern gama grass, *Tripsacum dactyloides*	312	6.2	13.5	72.2	8.1	76.3
Eastern gama grass, *Tripsacum dactyloides*	281	8.2	12.0	67.5	12.3	73.9
Goose grass, *Eleusine indica*	143	7.2	11.4	72.1	9.3	76.7
Indian grass, *Sorghastrum nutans*	189	8.4	14.8	69.8	7.0	73.3
Johnson grass, *Sorghum halepense*	—	6.7	12.4	74.4	6.5	77.7
Love grass, South African, *Eragrostis curvulla*	178	7.6	11.4	72.7	8.3	76.9
Panicum grass, Lindheimer's, *Panicum Lindheimeri*	148	7.2	10.3	74.5	8.0	78.5
Paspalum grass, Combs', *Paspalum almum*	292	5.1	16.9	68.0	10.0	73.0
Paspalum grass, Lang's, *Paspalum Langei*	314	5.3	12.5	74.8	7.4	78.5
Paspalum grass, ribbed, *Paspalum malacophyllum*	257	4.3	11.9	73.4	10.4	78.6
Purple topgrass, *Triodia flava*	143	5.8	11.3	75.5	7.4	79.2
Rhodes grass, *Chloris gayana*	219	4.0	11.1	73.1	11.8	79.3
Rhodes grass, *Chloris gayana*	297	5.3	12.2	70.8	11.7	76.7
Stick grass, *Panicum antidotale*	293	3.2	11.1	74.5	11.2	80.1
Cynodon plactostachyum	98	5.9	14.0	73.3	6.8	76.7
Eriochloa sericea	255	4.4	13.7	74.6	7.3	78.2
Paspalum stramineum	290	3.8	12.1	76.1	8.0	80.1
Alfalfa, *Medicago sativa*	204	10.8	9.5	74.7	5.0	77.2
Bur clover, *Medicago hispida*	400	3.7	0.0	89.1	7.2	92.7
Average (31) bur clover omitted		6.4	12.1	72.7	8.8	77.1
Average, corrected for impurity A			12.9	77.7	9.4	82.4

samples of these grasses than among samples of fresh green grasses. Even with these greater variations, the beta-carotene equivalents of 9 of the 13 grasses could be calculated from the crude carotene by use of

TABLE 2.—*Carotenoid constituents of crude carotene fractions from dried and dormant grasses and silages.*

Common and botanical names	Crude carotene dry basis, p.p.m.	Percentage of constituents of crude carotene				
		Impurities A	Neo-beta-carotene U	Beta-carotene	Neo-beta-carotene B	Beta-carotene equivalent
Young Grasses Dried at 65°C						
Bermuda grass, *Cynodon dactylon*	99.0	11.2	16.8	62.0	10.0	67.0
Buffalo grass, *Buchloe dactyloides*	83.4	12.9	16.5	59.5	11.1	65.1
Crab grass, *Digitaria sanguinalis*	111.7	10.9	14.3	64.5	10.3	69.7
Dallis grass, *Paspalum dilatatum*	75.4	12.4	14.9	63.3	9.4	68.0
Eastern gama grass, *Tripsacum dactyloides*	128.0	11.0	17.2	61.4	10.4	66.6
Rhodes grass, *Chloris gayana*	126.0	10.1	14.5	64.9	10.5	70.2
Average of 6		11.4	15.7	62.6	10.3	67.8
Average, corrected for impurity A			17.7	70.7	11.6	76.5
Dormant Grasses						
Beard grass, Australian, *Andropogon intermedius*	8.0	43.7	12.4	37.2	6.7	40.6
Bermuda grass, *Cynodon dactylon*	23.1	21.3	10.1	49.6	10.0	54.6
Bluestem, big, *Andropogon provincialis*	8.5	50.0	13.0	30.0	7.0	33.5
Bristle grass, plains, *Setaria macrostachys*	28.4	15.9	15.3	59.2	9.6	64.0
Buffalo grass, *Buchloe dactyloides*	29.4	19.8	20.4	52.8	7.0	66.3
Crab grass, *Digitaria sanguinalis*	14.2	37.4	13.7	41.5	7.4	45.2
Eastern gama grass, *Tripsacum dactyloides*	54.8	16.8	16.5	58.2	8.5	62.7
Indian grass, *Sorghastrum nutans*	71.6	18.8	18.2	57.1	5.9	60.1
Love grass, South African, *Eragrostis curvulla*	17.6	25.8	15.9	48.2	10.1	53.3
Paspalum grass, Lang's, *Paspalum Langei*	36.6	14.8	16.5	60.8	7.9	64.8
St. Augustine grass, *Stenotaphrum secundatum*	58.0	19.0	14.5	60.6	5.9	63.6
Stick grass, *Panicum antidotale*	23.1	28.1	13.0	52.8	6.1	55.9
Paspalum stramineum	33.2	20.1	15.0	56.1	8.8	60.5
Average of 13		25.5	15.6	51.1	7.8	55.8
Average, corrected for impurity A			20.1	68.6	10.5	74.9
Silages						
Sumac sorghum silage 1942–May 1943	55.8	45.6	19.0	31.0	4.4	33.2
Sumac sorghum silage 1941–Nov. 1943	39.5	50.9	13.0	30.3	5.8	33.2
Sumac sorghum silage 1941–Dec. 1943	42.0	62.7	10.3	23.5	3.5	25.3
Sumac sorghum silage 1943–Nov. 1943	40.7	41.0	12.0	40.0	7.0	43.5
Sumac sorghum silage 1943–Dec. 1943	25.7	59.0	11.4	24.2	5.4	26.9
Hegari silage 1942–May 1943	17.6	52.5	19.9	19.5	8.1	23.6
Hegari silage 1943–Nov. 1943	15.3	46.7	12.7	33.8	6.8	37.2
Hegari silage 1943–Dec. 1943	20.5	49.7	15.5	28.6	6.2	31.8
Average of 8		51.0	14.2	28.9	5.9	31.8
Average, corrected for impurity A			29.0	59.0	12.0	64.9

the factor 0.56 with an error of 10% or less. The two dormant grasses which were lowest in percentage of beta-carotene equivalent contained only 8.0 and 8.5 p.p.m. of crude carotene. The percentages of impurity A were 43.7 and 50.0 as compared with a 25.5% group average, and beta-carotene equivalents were 33.5% and 40.6% as compared with a group average of 55.8%. Grasses which are very low in carotene may thus have a very impure crude carotene.

When impurity A is excluded, neo-beta-carotene U is much higher in dormant grasses than in fresh or dried grasses, while neo-beta-carotene B is nearly the same.

The silages were put in the silo in September of the year first given in Table 2 and the samples were taken out in the month and year named next. The crude carotenes of all samples had high contents of impurity A, averaging 51%. Neo-beta-carotenes U and B, respectively, averaged 14.2% and 5.9% of the crude carotene. This is nearly the same as in the dormant grasses. If impurity A is excluded, the proportion of neo-beta-carotene U in the silages is appreciably higher than in the dormant grasses. The beta-carotene equivalent was variable and averaged only 31.8%, with a standard deviation of 6.6%.

SUMMARY

Fresh green forages contained from 98 to 400 p.p.m. crude carotene on the dry basis. The crude carotene, on the average, contained 6.4% of impurity A, 12.1% of neo-beta-carotene U, 72.7% beta-carotene, and 8.8% neo-beta-carotene B. The average beta-carotene equivalent of the fresh grasses was 77.1%, with a standard deviation of 2.6%.

The percentages of impurity A and of neo-beta-carotenes U and B were higher in dried grasses than in fresh grasses. The average beta-carotene equivalent of the dried grasses was 67.8% with a standard deviation of 1.9%.

Dormant grasses contained from 8.0 to 71.6 p.p.m. crude carotene. The average percentages of impurity A, neo-beta-carotene U, beta-carotene, and neo-beta-carotene B were 25.5, 15.6, 51.1, and 7.8, respectively. The average beta-carotene equivalent was 55.8%, with a standard deviation of 10.0%.

The crude carotene of silages contained an average of 51.0% of impurity A, 14.2% of neo-beta-carotene U, 28.9% of beta- carotene, and 5.9% of neo-beta-carotene B. The average beta-carotene equivalent was 31.8% with a standard deviation of 6.6%.

LITERATURE CITED

1. BEADLE, B. W., and ZSCHEILE, F. P. Studies on the carotenoids. II. The isomerization of beta-carotene and its relation to carotene analyses. Jour. Biol. Chem., 144:21–33. 1942.
2. KEMMERER, A. R., and FRAPS, G. S. Constituents of the carotene extracts of plants. Ind. & Eng. Chem., Anal. Ed., 15:714–716. 1943.
3. ———, ———. The nature of carotene in alfalfa. Jour. Amer. Chem. Soc., 66:305–306. 1944.
4. ———, FUDGE, J. F., and FRAPS, G. S. Carotene content of Texas range forages. Jour. Amer. Soc. Agron., 34:851–855. 1942.
5. POLGAR, A., and ZECHMEISTER, L. Isomerization of beta-carotene. Isolation of a stereoisomer with increased adsorption affinity. Jour. Amer. Chem. Soc., 64:1856–1861. 1942.

THE EFFECT OF POTASH LEVEL ON SEVERAL CHARACTERS IN FOUR STRAINS OF UPLAND COTTON WHICH DIFFER IN FOLIAGE GROWTH[1]

J. H. TURNER, JR.[2]

COTTON rust, attributed to a deficiency of potash, is common in the Coastal Plain of Georgia. Even when 40 to 60 pounds per acre of potash are applied, the deficiency symptoms occur in cotton grown on many soils. Defoliation, shriveled bolls, and reduced yields are the general results. Observations indicate that the severity of potash-deficiency symptoms differ in cotton varieties. Light-foliaged varieties seem to show earlier deficiency symptoms and varieties with largest leaf area remain normal longer and give larger yields when potash is deficient.

Previous studies at the Georgia Coastal Plain Experiment Station have indicated that heavy-foliaged strains shed less than light-foliage types, regardless of weevil population or seasons. Isely (1)[3] in Arkansas has shown that leaf size has little influence upon weevil damage where plants were of the same size.

The results of experiments reported in this paper show the effect of potash on plant foliage and factors associated with cotton yield on four strains of upland cotton. The experiments were made on Tifton sandy loam at the Coastal Plain Experiment Station, Tifton, Ga.

REVIEW OF LITERATURE

Numerous experiments have been conducted studying the value of potash applications to the cotton crop; most of these, however, have not been concerned with different types or strains of cotton.

Moore and Rankin (2), at the North Carolina Experiment Station, found that relationships did exist between potash applications and yield and boll and seed characters of cotton. In a study of exchangeable potassium in Alabama soils, Volk (4) concluded that higher potash applications resulted in later maturity and heavier weevil infestation and, consequently, gave lower yields in many localities.

Potash-varietal-wilt studies conducted in Alabama by Tisdale and Dick (3) showed that varieties differ as to potash requirements. Their work also indicated that only moderate applications of potash were profitable.

MATERIALS AND METHODS

The land selected for this study grew Spanish peanuts the two preceding years. The peanuts received applications of a 2–10–4 fertilizer at a rate of 400 pounds per acre. In the study, reported here, potash was applied at the rates of 20, 40, and 80 pounds of K_2O per acre, secured from applications of 3–8–4, 3–8–8, and 3–8–16 fertilizer mixtures, respectively, applied at the rate of 500 pounds per acre. The nitrogen in these formulas was obtained in the following way: 40% from 16% nitrate of soda, 40% from 42% uramon, and 20% from 7% cottonseed meal. The phosphorus was derived entirely from 16% superphosphate and the potash was obtained from 50% muriate of potash in all instances.

[1]Contribution of the Department of Agronomy, Georgia Coastal Plain Experiment Station, Tifton, Ga. Received for publication March 20, 1944.

[2]Agronomist (Cotton Breeding). The author is indebted to Dr. G. W. Burton for aid and suggestions in preparation of the manuscript.

[3]Figures in parenthesis refer to "Literature Cited", p. 698.

All fertilizers were weighed and applied by row and bedded-on 10 days to 2 weeks previous to planting.

Characteristics of the four strains of cotton grown are as follows: Station 21 has a large leaf, with heavy foliage. It is medium to late in maturing. Station C has a medium size leaf, produces a medium amount of foliage, and is unusually early in maturing. Station S has a small leaf, produces a small amount of foliage, and is early in maturing. Coker's 4 in 1 strain 4 has a large leaf and produces a medium to heavy foliage. The maturity of this strain is about the same as that of Station 21 and the foliage is intermediate between Station 21 and Station C. All seed were Ceresan treated.

Calcium arsenate dust was applied four times each season. The first dust was applied at squaring and the last dusting came as flower production diminished. Treatments and strains remained on the same plots for the 3 years of the experiment and all notes were taken in a consistent manner for the entire study.

A factorial design was used which consisted of four cotton strains and three levels of potash in four randomized blocks. Each plot was 1/100 acre. Records were made of plant emergence, stand, daily bloom, leaves shed by time of first picking, and yields. Boll samples were taken at time of first and second pickings.

EXPERIMENTAL RESULTS

NUMBER OF BLOOMS PRODUCED

Flower production data showed differences for seasons, strains, and treatments. The daily bloom counts were totaled for each plot and calculated upon an acre basis. The results are found in Table 1.

Potash gave different results for the various years in bloom production. A significant decrease in blooms occurred in 1941 as potash increased from 20 to 80 pounds per acre, whereas significant increase was found in 1942 for the same treatments.

Strain differences shown in bloom production were relatively the same for the 3 years. Station C and Station S gave significantly higher bloom production than Coker's 4 in 1 and Station 21, with Station 21 being low in all cases. The 3-year averages showed a difference between the heavy- and light-foliaged strains of 45,900 blooms per acre in favor of the light-foliaged strain. All of the strain means tended to comply with this relationship; that is to say, bloom production increased as foliage diminished.

Varietal-treatment means showed that Station 21 and Coker's 4 in 1 tended to decrease in bloom production with higher applications of potash, whereas Station C and Station S showed increases in this respect. The mean squares from the analysis of variance given in Table 6 show no significant differences for strain × treatment interaction. Even so, the 3-year averages show that Station C was significantly higher in bloom production at the 80-pound level, producing 44,950 more blooms per acre than Station 21, but no significant differences were present at the 20-pound potash level.

LEAF LOSS FROM "RUST"

Potash deficiency, or "rust", as it is commonly called, is manifested in the cotton leaves toward the end of the fruiting period. Rusty fields are more common in years which are favorable for a heavy set of fruit. Usually the fields which are noticeably rusty and have lost a large portion of the leaves can be expected to be deficient in potash either because of rotation practices or from low rates of potash

TABLE 1.—*Effect of potash on cotton blooming.*

Strain	Blooms per acre in thousands with K_2O applied at acre rate of 20 lbs.	40 lbs.	80 lbs.	Strain means
	1941			
Station 21	239	232	212	228
Station C	245	240	248	244
Station S	246	254	227	242
4 in 1 No. 4	247	245	214	235
Treatment mean	244	243	225	
	1942			
Station 21	141	143	153	146
Station C	175	190	196	187
Station S	193	202	199	198
4 in 1 No. 4	161	174	174	170
Treatment mean	167	177	180	
	1943			
Station 21	180	180	180	180
Station C	208	215	237	223
Station S	247	245	260	250
4 in 1 No. 4	207	206	185	199
Treatment mean	210	211	216	
	3-year Average			
Station 21	187	185	182	184
Station C	209	215	227	217
Station S	229	234	229	230
4 in 1 No. 4	205	208	191	201
Treatment mean	207	211	207	

Least significant differences at 5% point	Varietal treatment means (n = 4)	Varietal means (n = 12)	Treatment means (n = 16)
1941	23	13	11
1942	20	11	10
1943	21	12	10
3-year average	28	16	14

fertilizer applied. The early loss of leaves probably has a great deal of influence upon a number of other characters, such as ease of picking, boll size, fiber, and seed quality.

The percentage of leaves lost at time of first picking was recorded for all plots during this study. These data are given in Table 2. "Rust" was more severe in 1941 than for the last 2 years. Evidently the heavier set of bolls for that season had much to do with this difference.

TABLE 2.—*Effect of potash on defoliation at time of first picking.*

Strain	Percentage of leaves lost with K_2O applied at acre rate of			Strain means
	20 lbs.	40 lbs.	80 lbs.	
1941				
Station 21	75.0	56.2	21.3	50.8
Station C	91.3	77.5	50.0	72.9
Station S	90.0	82.5	56.3	76.3
4 in 1 No. 4	62.5	62.5	31.3	52.1
Treatment mean	79.7	69.7	39.7	
1942				
Station 21	45.0	37.5	30.0	37.5
Station C	67.5	57.5	45.0	56.7
Station S	87.5	77.5	55.0	73.3
4 in 1 No. 4	52.5	50.0	37.5	46.7
Treatment mean	63.1	55.6	41.9	
1943				
Station 21	32.5	23.8	10.0	22.1
Station C	56.3	32.5	10.0	32.9
Station S	78.8	52.5	21.3	50.8
4 in 1 No. 4	37.5	23.7	10.0	23.8
Treatment mean	51.3	33.1	12.8	
3-year Average				
Station 21	50.8	39.1	20.4	36.8
Station C	71.7	55.8	35.0	54.1
Station S	85.4	70.8	44.1	66.8
4 in 1 No. 4	50.8	45.4	26.2	40.8
Treatment mean	64.7	52.8	31.4	

Least significant differences at 5% point	Varietal-treatment means ($n = 4$)	Varietal means ($n = 12$)	Treatment means ($n = 16$)
1941	16.4	10.0	8.7
1942	7.4	4.3	3.7
1943	10.6	6.1	5.3
3-year average	5.5	3.2	2.8

There were significant differences between all strains, with the heaviest foliaged strain showing the least percentage of leaf loss. In this study there appeared to be a close relationship between leaf loss and foliage type.

The highly significant differences in potash levels indicated that heavy applications of potash might be expected to reduce the amount of leaf loss considerably. The 3-year averages for treatments showed

a 64.7% leaf loss for the 20-pound level as compared with 31.4% leaf loss for 80 pounds of potash.

YIELD OF SEED COTTON PER ACRE

The yearly results and 3-year averages, giving pounds of seed cotton per acre for each strain and potash treatment as well as least significant differences, are shown in Table 3.

TABLE 3.—*Effect of potash on total yield.*

Strain	Pounds of seed cotton per acre with K_2O applied at acre rate of 20 lbs.	40 lbs.	80 lbs.	Strain means
		1941		
Station 21	944	1,122	1,341	1,135
Station C	1,015	1,208	1,482	1,235
Station S	809	1,005	1,099	971
4 in 1 No. 4	1,063	1,138	1,200	1,133
Treatment mean	958	1,118	1,280	
		1942		
Station 21	841	1,048	1,273	1,054
Station C	868	978	1,146	997
Station S	647	817	942	802
4 in 1 No. 4	827	991	1,129	982
Treatment mean	796	958	1,122	
		1943		
Station 21	725	958	1,173	952
Station C	851	1,003	1,132	995
Station S	614	804	938	786
4 in 1 No. 4	824	983	1,087	965
Treatment mean	753	937	1,082	
		3-year Average		
Station 21	837	1,042	1,262	1,047
Station C	911	1,063	1,253	1,076
Station S	690	875	993	853
4 in 1 No. 4	904	1,037	1,139	1,027
Treatment mean	836	1,004	1,161	

Least significant differences at 5% point	Varietal-treatment means (n = 4)	Varietal means (n = 12)	Treatment means (n = 16)
1941	151.6	87.5	75.7
1942	110.9	64.1	55.5
1943	118.8	68.5	59.4
3-year average	120.3	66.7	59.8

From these data it is apparent that rather high significant differences occurred in all instances between potash levels. (See Fig. 1.) It is interesting to note that increases in seed cotton yields from the second increment of potash were approximately the same as the gain received from the first increase of potash level. Also, in regard to treatment effect, the yields for the second and third years fail to indicate any accumulation of potash from plots having received the highest levels of potash. Yield differences for the 3 years seem to be largely due to the fact that the most favorable cotton season was in 1941. Excessive rainfall during the summer months of 1943 resulted in the lowest cotton yields for several years.

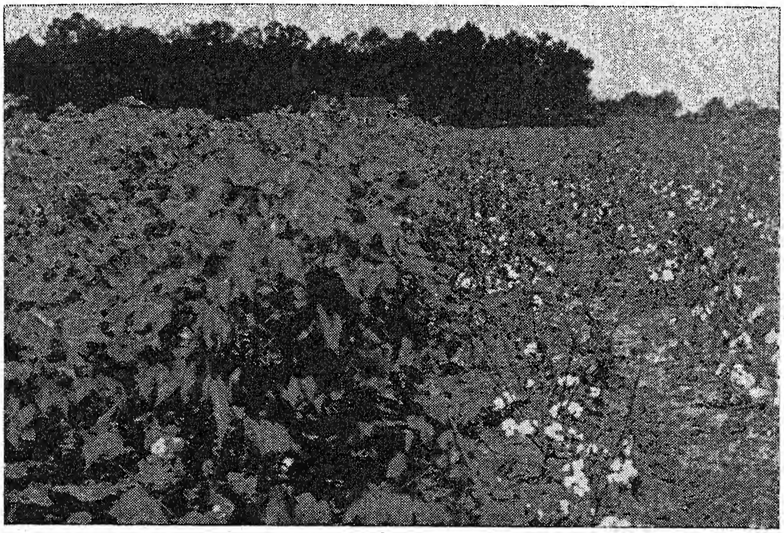


FIG. 1.—*Left*, Station C with 80 pounds of K_2O in 1941; *right*, Station C with 20 pounds of K_2O in 1941.

Strain differences shown in Table 3 were not as constant as the treatments. Nevertheless, it is evident that Station S gave significantly lower yields than the other strains. When considering the 3-year average yields, no significant differences were found among the three strains of heavier foliaged growth. The higher yield of Station C in 1941 may be due largely to differences in seedling vigor for that season. Dry weather prevailed between date of fertilizer application and time of planting. Station C seemed to be affected less than other strains in this respect. Seedling vigor did not differ in the other years.

Strain treatment means for the 3-year average fail to show significant differences between the heavy and medium foliaged cottons. Yet a study of yields from 20 to 80 pounds of potash shows that increases were considerably more for Station 21 than for Station C or 4 in 1.

MEASURES OF PRODUCTION EFFICIENCY

Several characters need to be considered to understand the relation of bloom production to final yields secured. A better understanding of final yields was made possible from studying boll size, shedding, and number of bolls maturing.

Table 4 gives 3-year average values for boll size and other characters of importance with least significant differences for each.

TABLE 4.—*Means for variables obtained in a study of the influence of three different acre rates of potash applications on four strains of cotton, 1941–43.*

Strain	Boll weight, grams				Potential yield of seed cotton per acre, lbs.				Number of blooms per pound of seed cotton			
	20 lbs.	40 lbs.	80 lbs	Mean*	20 lbs.	40 lbs.	80 lbs.	Mean*	20 lbs.	40 lbs.	80 lbs.	Mean*
Station 21	6.03	6.31	6.47	6.27	2,480	2,559	2,621	2,551	224	176	144	182
Station C	5.18	5.55	5.91	5.55	2,437	2,647	2,959	2,681	227	200	180	203
Station S	4.88	5.23	5.41	5.18	2,473	2,721	2,722	2,638	336	270	232	280
4 in 1 No. 4	5.49	5.75	5.99	5.75	2,513	2,674	2,527	2,575	227	200	168	198
Treatment mean†	5.40	5.71	5.94	—	2,476	2,650	2,710	—	254	212	181	—

*Least significant difference, odds 19:1, strain means; boll significance, 0.16; yield, pounds, 66; blooms per pounds of seed cotton, 7.

†Least significant difference, odds 19:1, treatment means; boll size, grams, 14; yield, pounds, 56; blooms per pounds of seed cotton, 60.

The average boll weight was determined from samples gathered before the two pickings for each plot. These samples were taken from the lower and upper sections of the plant and were given equal weight in determining average boll size since no significant differences for picking $\times$strain or picking $\times$ treatment were present.

Significant increases in boll size were shown with increasing potash levels. All strains increased in boll size with added potash. There was a wide range in boll size from 6.27 grams per boll for Station 21 to 5.18 grams for Station S.

Potential yields were calculated by multiplication of bloom production and the average boll size for each plot. The 3-year average potential yields are also given in Table 4. Only slight differences are shown in the potential yield for the various strains even though Station S, with a mean of 2,638, and Station C with a mean of 2,681 were significantly higher than Station 21 with a mean of 2,553. However, the analysis of variance for the 3-year potential yields (mean squares in Table 6) failed to show any significance for strains as a whole. It seems likely from this analysis that all strains would be expected to have produced approximately the same yields if it were possible for all blooms to have produced mature bolls. Treatments gave significant differences in potential yield with each level of potash causing increases in this respect. However, all strains did not

act alike in this respect. For instance, Station C gave proportionate increases for each increment of potash, while 4 in 1 and Station S gave no increases above the 40-pound level of potash.

The actual number of bolls to set and mature is the only character left that might explain differences in seed cotton yield, since boll size and bloom production resulted in practically the same potential yields. Mature bolls were not counted for the first 2 years of this study, but accurate counts were made of the bolls on each plot previous to

TABLE 5.—*Effect of potash on the efficiency of boll setting.*

Strain	Calculated percentage blooms to set bolls with K_2O applied at acre rate of			Strain means
	20 lbs.	40 lbs.	80 lbs.	
		1941		
Station 21	27.2	31.9	38.5	32.6
Station C	33.5	37.5	41.0	37.3
Station S	26.2	28.8	34.6	29.9
4 in 1 No. 4	31.2	31.9	37.7	33.6
Treatment mean	29.5	32.5	38.0	
		1942		
Station 21	46.7	54.1	60.3	53.7
Station C	43.9	43.8	46.8	44.8
Station S	33.8	37.7	44.4	38.3
4 in 1 No. 4	44.9	47.6	51.3	48.0
Treatment mean	42.4	45.8	50.4	
		1943		
Station 21	34.4	44.5	52.1	43.7
Station C	37.2	40.9	40.4	39.5
Station S	25.7	32.5	33.7	30.6
4 in 1 No. 4	36.7	41.1	49.3	42.4
Treatment mean	33.5	39.8	43.9	
		3-year Average		
Station 21	34.0	40.9	48.3	41.0
Station C	37.4	40.4	42.3	40.1
Station S	28.0	32.2	36.6	32.3
4 in 1 No. 4	36.1	36.2	44.9	40.0
Treatment mean	33.9	38.1	43.0	

Least significant differences at 5% point	Varietal-treatment means (n=4)	Varietal means (n=12)	Treatment means (n=16)
1941	4.5	2.6	2.3
1942	4.9	2.8	2.4
1943	4.9	2.8	2.4
3-year average	2.1	1.2	1.1

the 1943 harvest. These figures were analyzed and gave highly significant differences for strain and treatments in the percentage of blooms to mature bolls.

An index figure, termed "setting efficiency", was compared with the 1943 percentage of blooms to set and showed close correlation. Therefore, setting efficiency, $\frac{(\text{actual yield} \times 100)}{(\text{potential yield})}$, for the 3 years is given in Table 5. These figures show that setting ability accounted to a large extent for differences which occurred in seed cotton yields. Station 21 was 27% more efficient than Station S and produced 21% more seed cotton. Treatment means also showed significant increases in setting efficiency for increased potash.

Another measure of production efficiency worthy of consideration was the number of blooms required to produce each pound of seed cotton. Such a figure was found by dividing actual yields by the total blooms for each plot. This measure does not distinguish between the portion of the differences due to boll size and that due to number of bolls maturing.

The number of blooms required to produce a pound of seed cotton is also given in Table 4. The differences which occur for both strains and treatments are highly significant. From these averages it can be seen that over 50% more blooms were required for Station S than was the case with Station 21. Treatment means show that 40% more blooms were required to produce a pound of seed cotton with 20 pounds of potash per acre than for the 80-pound level of potash.

MEAN SQUARES OF VARIABLES

Mean squares from the analysis of variance for the total of the 3 years are given in Table 6. The lower section of this table gives the interaction of years. Reference has already been made to certain mean squares found in this table. The three findings of greatest interest were as follows:

1. Highly significant differences between strains were present for all measures except potential yield. The lack of significance in this measure is attributed to the fact that boll size for the various strains was inversely related to the number of blooms produced.

2. There were highly significant differences between treatment for all variables except bloom production. Seasons seemed to play an important role in number of flowers.

3. The strain × treatment interaction was significant for the variables which are measures of production efficiency.

SUMMARY

1. Four strains of upland cotton, differing in foliage characteristics, were studied for three consecutive years at three levels of potash fertilizer.

2. Significant increases in yield of seed cotton per acre were shown between 20-, 40-, and 80-pound levels of potash.

TABLE 6.—*Mean squares of variables obtained in a study of the influence of potash on four strains of cotton, 1941–43.*

Variation due to	Degrees freedom	Yield of seed cotton per acre	Blooms per acre	Weight per boll	Potential yield per acre	Setting efficiency	Blooms required per pound of cotton	Leaf loss
				Average Effect of Treatments				
Replication	3	38421*	779474**	0.013	1084311	105.2	3291	287
Strain	3	364398**	1413025**	6.970**	123455	744.0**	50775**	6527**
Treatment	2	1276316**	18182	3.430**	710266**	964.5**	47577**	13388**
S × T	6	21419	65934	0.030	171905*	51.3*	1549*	249
Error	33	13891	34976	0.040	56103	19.4	584	131
Total	47	—	—	—	—	—	—	—
				Interaction of Treatments With Years				
Years	2	515380**	2555768**	23.44**	21574867**	1990.4**	27611**	11799**
Rep. × Yrs.	6	12565**	167733**	0.04	231051	18.4*	452	185
Str. × Yrs.	6	14265*	186061**	0.34**	299645**	140.2**	5444**	273
Tr. × Yrs.	4	758	123351**	0.11**	97307*	13.9	1757*	659
S × T × Yrs.	12	7108	3093	0.03	48736	10.8	368	111
Error	66	4961	17401	0.04	35935	6.4	257	381
Total	143	—	—	—	—	—	—	—

*Significance, odds: 19:1
**Significance, odds: 99:1

3. Highly significant differences were found to exist between the light foliaged strain and the three strains of heavier foliage. Differences of significance were not general between the three strains of heavier foliaged growth, but trends were observed which indicated that the heaviest foliaged strain gave the largest response to higher potash levels.

4. The lightest foliaged strain showed a significantly greater bloom production than the heavy foliaged types.

5. No definite effect of bloom production was identified with potash levels.

6. Significant increases in boll size were found when potash was increased. Significant differences were also found between all strains, with the average boll size becoming larger as density of foliage increased.

7. The various measures of production efficiency may be summarized by stating that high bloom production was not indicative of high yields, that different foliaged types showed significant differences in setting efficiency, and that higher levels of potash were of significant benefit in setting more fruit. Strain × treatment interactions were significant for all measures of production efficiency.

8. Leaf loss was significantly lower for the higher levels of potash. Light-foliaged types lost the most leaves. Significant differences were present between each strain, with leaf loss diminishing as density of foliage increased.

LITERATURE CITED

1. ISELY, DWIGHT. The relation of leaf color and leaf size to boll weevil infestation. Jour. Econ. Ent., 21:553–559. 1928.
2. MOORE, J. H., and RANKIN, W. H. Influence of "rust" on quality and yield of cotton and the relation of potash to control. N. C. Agr. Exp. Sta., Bul. 308. 1937.
3. TISDALE, H. B., and DICK, J. B. Cotton wilt in Alabama as affected by potash supplements and as related to varietal behavior and other important agronomic problems. Jour. Amer. Soc. Agron., 34:405–426. 1942.
4. VOLK, N. J. Relation of exchangeable potassium in Alabama soils to needs of the cotton crop. Jour. Amer. Soc. Agron., 34:188–198. 1942.

PRELIMINARY TRIALS ON THE EFFECT OF MANAGEMENT ON THE ESTABLISHMENT OF PERENNIAL GRASSES AND LEGUMES AT DAVIS, CALIFORNIA[1]

R. MERTON LOVE[2]

ANNUAL grasses and herbs constitute a preponderance of the vegetative cover on the foothill ranges of California, although Piemeisel and Lawson (2)[3] concluded from their studies of the vegetation of the San Joaquin Valley that, "the type was originally a cover of perennial bunch grasses." These have now almost entirely disappeared. Weaver and Clements (5) considered *Stipa pulchra* Hitchc. to be the former dominant and this has since been shown (3) to be comprised of two distinct species, namely, *S. pulchra* Hitchc. and *S. cernua* Stebbins and Love.

The chief drawbacks to the annual vegetation in California are (a) the annuals pass through their life cycle very rapidly and set seed and die shortly after the rainy season ends in the spring; (b) the wide fluctuations from year to year in the botanical composition of the annual cover (4) result in range deterioration since the same numbers of livestock tend to be carried in good years and bad; and (c) annuals are not as effective as perennials in preventing run-off and erosion, as has been pointed out by Chapline and Cooperrider (1) and others.

One of the major obstacles to be overcome in improving the range is the re-establishment of perennial grasses. The slower rate of growth of their seedlings is a marked handicap to their survival in a dense stand of resident annuals. In order to determine the effects of different management practices on freshly seeded perennials the experiment described below was set up.

The 27-acre field used for the experiment had been dry-farmed for years prior to 1933 after which it was pastured until 1935. From 1936 to 1942 it was used for increasing cereal varieties, a year of cropping alternating with one of fallow. In 1942 the cereals increased were varieties of wheat, oats, and barley. The soil is a Yolo clay loam and has a high water-holding capacity. The season 1942–43 was normal with respect to the amount and distribution of rainfall, but there were more killing frosts in January than usual (Table 1).

PLAN OF EXPERIMENT

In 1942, before the advent of the fall rains, the 27-acre field was disked to a depth of 3 or 4 inches and, except for three areas reserved for plots, was seeded broadcast with a mixture of perennial ryegrass, *Lolium perenne* (6 pounds per acre), annual ryegrass, *L. multiflorum* (3 pounds), and bur clover, *Medicago hispida* (10 pounds). In addition, over the field (including the plots) there was a volunteer seeding of wheat, oats, and barley estimated to be at the rate of 25 to 45 pounds per acre. The rains beat in the seed.

Three sets of 34 plots, 10 feet × 43.5 feet (about 0.01 acre) were seeded broadcast November 23, 1942, to five legumes, burnet (a member of the Rose family),

[1]Contribution from the Division of Agronomy, University of California, Davis, Calif. Received for publication March 27, 1944.

[2]Assistant Professor of Agronomy.

[3]Numbers in parenthesis refer to "Literature Cited", p. 703.

and 11 grasses, including nodding and purple Stipas, *Stipa cernua* and *S. pulchra*. Seventeen plots of the series were seeded with *S. cernua* and a parallel set of 17 with *S. pulchra* at the rate of 6.25 pounds per acre. One other grass or legume was seeded on each plot at the same rate (Table 2). In March, 1943, before any grazing had occurred, the area was divided into three fields of 9 acres each so that each field contained one set of 34 plots.

TABLE 1.—*Climatological data, Davis, Calif., September, 1942, to August, 1943.*

Month	Precipitation, inches	Evaporation, inches	Temperature, °F				Date of killing frosts
			Maximum	Mean maximum	Minimum	Mean minimum	
			1942				
Sept...	0.02	7.580	106.0°	89.5°	45.0°	49.7°	—
Oct....	0.59	5.122	94.8°	82.9°	36.5°	46.2°	—
Nov....	1.65	2.015	82.0°	66.9°	28.0°	38.6°	26
Dec....	2.66	0.702	72.0°	56.0°	27.0°	36.8°	4, 6
			1943				
Jan....	7.67	1.952	67.0°	57.6°	21.0°	35.7°	7–20, incl.
Feb....	1.23	1.541	74.0°	62.3°	28.0°	38.6°	1, 2, 9, 10, 11
Mar....	2.30	2.612	75.0°	65.9°	34.0°	41.6°	—
Apr....	1.44	5.227	83.0°	72.8°	34.0°	44.3°	—
May...	0.25	9.782	100.0°	83.5°	38.0°	50.6°	—
June...	0.06	9.614	104.0°	84.8°	41.0°	50.3°	—
July ...	0.00	10.986	108.0°	95.5°	49.0°	55.5°	—
Aug....	0.00	9.845	106.0°	92.7°	46.0°	51.7°	—

Three different management practices were pursued the first year following seeding. The farm flock of sheep was used and, for purposes of record, the animals were weighed before and after each grazing period. These data are not included here since, due to the heavy volunteer stand of cereals, the gains were greater than could normally be expected. Suffice to say that the gains were greatest with the treatment that resulted in the best stand of perennials. The writer is pleased to acknowledge the cooperation of Prof. R. F. Miller of the Division of Animal Husbandry who provided and weighed the sheep.

FIELD 1 — EARLY GRAZING

The three 9-acre fields received the same treatment until April 2, 1943, when 275 ewes and lambs were turned into field 1. At that date there was a fair to good stand of the seeded species in all fields, the cereals were 12 to 18 inches high, the bur clover formed a dense undercover and was flowering, but the perennial grasses were still small seedlings 1 or 2 inches high. Grazing in field 1 was continued until April 20 at which time the ryegrasses and cereals had been grazed to a fairly uniform height of 4 to 8 inches and the bur clover had been closely cropped. The slower growing perennials had not been grazed to any appreciable extent. On April 22 the stand of the seeded species was fair to good and they varied in height from 4 to 8 inches. By July 5, however, they were from 6 to 30 inches tall and most of the perennial species were setting seed.

When 83 ewe lambs were turned back into field 1 on July 27 all perennials were ripe and the secondary growth of the ryegrasses, cereals, and bur clover had matured seed. The field was well cleaned up on August 24 when the lambs were removed.

FIELD 2 — LATE GRAZING

On April 20, 264 ewes and lambs were turned into field 2. The volunteer cereals were about 3 feet high, the wheat and barley were in the dough stage, the rye-

grasses and bur clover had set seed, and the stand of seeded perennials varied from fair to good. The latter ranged in height from 3 to 6 inches, but many were already suffering from the severe competition. This flock was removed May 21, and in order to clean up more of the straw 83 dry ewes were put in and kept there until June 16.

Observations July 5 showed a poor to fair stand of the seeded perennials which were still only 3 to 8 inches high and most were not yet flowering.

TABLE 2.—*Summary of data recorded from line transects, September 23, 1943.*

Species	Number of plants touching line		
	Field 1 (grazed early)	Field 2 (grazed late)	Field 3 (mowed late)
Tall oatgrass, *Arrhenatherum elatius*	18	10	0
Tall fescue, *F. elatior var. arundinacea*	31	19	4
Annual ryegrass, *Lolium multiflorum**	—†	—†	—†
Perennial ryegrass, *L. perenne*	23	11	2
Birdsfoot trefoil, *Lotus corniculatus*	97	67	44
Burnet, *Sanguisorba minor* (Rosac.)	30	11	11
Nodding Stipa, *Stipa cernua*	50	5	5
Purple Stipa, *S. pulchra*	23	3	1
Persian clover, *Trifolium resupinatum**	—†	—†	—†
Subterranean clover, *T. subterraneum* var. Mount Barker*	—†	—†	—†
Yellow sweet clover, *Melilotus officinalis*	69	20	23
Orchard grass, *Dactylis glomerata*	13	8	0
Rhodes grass, *Chloris gayana*	0	0	0
Dallis grass, *Paspalum dilatatum*	4	1	0
Veldt grass, *Ehrharta calycina*	10	3	1
Barrel clover, *Medicago tribuloides**	—†	—†	—†
Agropyron × wheat derivative	2	4	2
Nodding Stipa (17 plots)	228	24	18
Purple Stipa (17 plots)	111	23	6
Perennial grasses other than Stipa (8 plots)	255	75	25

*Annual.
†Matured seed and were dead at time of count.

FIELD 3 — MOWING

The original plan was to mow field 3 the same day the animals were turned into field 1, but this could not be arranged. Since field 3 was not mowed until April 16, the results are not a fair comparison between mowing and early grazing, but it seems worthwhile to compare fields 2 and 3. After mowing, the hay was removed from the field. On April 22 the stand and development of the seeded perennials were essentially the same in fields 2 and 3.

On June 17, when 68 ewes were placed in field 3, the ryegrasses, cereals, and bur clover had recovered from the April 16 mowing which had little effect on the morning glory, *Convolvulus arvensis*, so that it provided severe competition for the perennials. The 68 ewes were removed from the field June 29 and were replaced by 35 ewes which remained in the field from July 2 to July 27. The July 5 observations showed a poor to fair stand of the seeded perennials which varied in height from 3 to 8 inches and few had flowered. Most of the plants were weak.

RESULTS AND DISCUSSION

In order to obtain a fairly accurate picture of the results of the different management treatments on the establishment of the various

grasses and legumes, line transects counts were made on the plots in all fields September 23, 1943. A tape measure was stretched diagonally across each plot and each live plant touching the line was recorded. The results are given in Table 2 which, incidentally, provides the reader with the plot lay-out in each field. It is seen, from the data recorded in Table 2, that the best results were obtained with the early, intensive grazing (field 1). The perennial legumes and burnet did better than the grasses in all fields, but even with these a better stand was obtained in field 1 that had the early, intensive grazing, followed by removal of the animals while there was still sufficient moisture available to ensure the continued development of the perennials. Rhodes and Dallis grass are obviously not adapted to dry-land conditions at Davis. The effect of the different treatments on the remainder of the slower growing grasses was striking. Apart from actual numbers, the vigor of the plants in the three fields differed markedly. Those in field 1 were healthy, vigorous plants at the end of the dry season in 1943, whereas those in the other two fields were poorly established with very weak root systems barely holding the crowns in contact with the soil.

This reseeding management experiment, the results of which are corroborated by those from smaller tests that have been conducted during the past 4 years at Davis and elsewhere in the state, indicates that the early spring following seeding is a very critical period in the life of the perennial. The fact that, during this critical period, the grazing animals did not damage the seedlings but, on the contrary, reduced the competition provided by the annuals, is a fundamental one and points the way to the improvement of the California range.

It must be recalled that these results have been obtained on good soil with a high water-holding capacity but, where proper management is helpful (as the results indicate) in the successful establishment of perennials on such soil, it would seem to be essential on poorer soils with a low water-holding capacity.

SUMMARY

Different grazing treatments in the spring following seeding of perennial grasses and legumes led to the following results:

1. Early, intensive grazing, before the annuals headed reduced the competition provided by them and resulted in the best stand of vigorous perennials. The removal of the animals before all available moisture was exhausted enabled the perennials to continue their development to maturity. A short period of grazing in the fall did not damage the young perennial plants.

2. Late grazing, beginning at the time the annuals were maturing, reduced the stands of perennial grasses by approximately 80% and perennial legumes by approximately 50%. Prolonged grazing into the dry season probably hindered further the development of the seeded species, which besides being reduced in numbers were much reduced in vigor.

3. Late mowing, followed by prolonged grazing, resulted in the poorest stand of the perennials.

LITERATURE CITED

1. Chapline, W. R., and Cooperrider, C. K. Climate and grazing. U. S. D. A. Yearbook of Agriculture, 1941:459–476. 1941.
2. Piemeisel, R. L., and Lawson, F. R. Types of vegetation in the San Joaquin Valley of California and their relation to the beet leafhopper. U. S. D. A. Tech. Bul. 577. 1937.
3. Stebbins, G. L., Jr., and Love, R. M. An undescribed species of Stipa from California. Madrono, 6:137–141. 1941.
4. Talbot, M. W., Biswell, H. H., and Hormay, A. L. Fluctuations in the annual vegetation of California. Ecology, 20:394–402. 1939.
5. Weaver, J. E., and Clements, F. E. Plant Ecology. New York: McGraw-Hill Book Co., Inc. Ed. 2. 1938.

A RAPID, FLUOROMETRIC METHOD FOR THE DETERMINATION OF COUMARIN AND RELATED COMPOUNDS IN SWEET CLOVER[1]

J. M. SLATENSEK AND E. ROGER WASHBURN[2]

A MODIFICATION of the colorimetric method developed by Clayton and Larmour (1)[3] is generally used for coumarin determination by sweet clover breeders in this country. It is based on the coupling reaction between coumarin and diazotized p-nitraniline in alkaline solution, the intensity of red color produced being compared colorimetrically with prepared standards for estimation of coumarin. On account of its complexity, the relatively large amounts of reagents and equipment needed, and the time and continuous attention required for each individual analysis, this method does not lend itself readily to investigations requiring the analysis of hundreds or thousands of plants. The rareness of low-coumarin plants in adapted, naturally high-coumarin varieties necessitates the analysis of large plant populations for the isolation of non-bitter, non-toxic sweet clovers (3). In addition to rapidity it is desirable that the method be inexpensive and simple enough to manipulate so that it can be performed by assistants lacking chemical experience.

A step toward the development of a method with such features was made as early as 1931 when Pavolini (2) reported on the detection of coumarin by means of the fluorescence produced on boiling with resorcinol. Later, Ufer (4) described a method of rapidly separating low from high coumarin plants by means of fluorescence produced when potassium hydroxide was added to the coumarin-containing leaf tissue.

The present investigation was conducted in an attempt to apply the fluorescence principle used in Ufer's method to a rapid, quantitative determination of coumarin. In addition to the making of rapid plant assays, a quantitative fluorescent method would make it possible to compare the colorimetric with the fluorometric method. In the method developed and given below sodium hydroxide, in aqueous solution, was used to convert the coumarin into the soluble and fluorescent salt. Concentration of coumarin was indicated by the intensity of fluorescence. This was measured either roughly by visual inspection under an ultra-violet lamp or quantitatively by means of a fluorometer, which afforded a rapid and accurate means of coumarin determination.

---

[1]Contribution from the Division of Forage Crops and Diseases, Bureau of Plant Industry, Soils, and Agricultural Engineering, Agricultural Research Administration, U. S. Dept. of Agriculture, the Department of Agronomy of the Nebraska Agricultural Experiment Station, and the Department of Chemistry, University of Nebraska, cooperating. Published with the approval of the Director of the Nebraska Agricultural Experiment Station, Lincoln, Nebr., as Journal Series Paper No. 345. Received for publication March 30, 1944.

[2]Assistant Agronomist, Division of Forage Crops and Diseases, Bureau of Plant Industry, Soils, and Agricultural Engineering, Agricultural Research Administration, U. S. Dept. of Agriculture, and Professor of Chemistry, University of Nebraska, respectively.

[3]Figures in parenthesis refer to "Literature Cited", p. 708.

PROCEDURE

Ten or more leaves are removed from the same relative position on each plant, placed in paper holders (used envelopes serve well), and left to dry at room temperature for 3 or 4 days. By this time the material is crisp and can easily be pulverized and mixed. A 100-mg sample of the pulverized plant material is placed in a dry 3/4 × 6 inch test tube marked for 15 ml. Then 2.5N NaOH is added to the 15 ml mark.[4] The tubes are loosely stoppered and placed in an oven or water bath maintained at a temperature of 95° C. After heating for 2 1/4 hours the tubes are removed from the oven, and if necessary, water is added to bring the solution to the 15 ml mark. After shaking, the samples are allowed to stand for a few minutes until the solids settle to the bottom. The samples are then ready to be examined for coumarin content either roughly with an ultra-violet lamp or quantitatively with a fluorometer.

ULTRA-VIOLET LAMP METHOD

A small amount of the supernatant liquid is poured into one of the depressions of a porcelain spot plate which is then placed under ultra-violet light in a dark room. Any type of ultra-violet lamp can be employed. It must, however, be fitted with a filter that will transmit ultra-violet light but absorb visible light. The presence of visible light from an improperly filtered ultra-violet lamp or from some other source will greatly decrease the ease of making observations. Lamps and filters can be purchased from several of the leading scientific supply houses.

The fluorometric method described is based on the principle that the sodium salt of coumaric acid, produced when coumarin-containing leaf tissue is heated with sodium hydroxide, fluoresces green. The intensity of the greenish fluorescence indicates the concentration of coumarin, coumaric acid, and possibly other closely related compounds in the plant samples. Chlorophyll in the plant tissue will produce a weak, dull-red fluorescence. Therefore, a sample with no coumarin will fluoresce dull red under the ultra-violet lamp, a sample with low coumarin will appear reddish green, while one of high coumarin will fluoresce brilliant green.

A feature of the fluorescence method is its extreme flexibility. Modifications of the procedure can be made which will permit the rapid classification of a considerable number of plants into high and low coumarin groups. At the Nebraska Station the following method, similar in most respects to that described by Ufer (4), is being used by the senior author for the preliminary elimination of plants in the search for non-toxic sweet clovers to be used in the breeding program. For this purpose a single, unweighed leaf of uniform size is removed from seedling sweet clover plants. The leaf is placed into a depression of a large spot plate capable of holding a hundred samples. After a solution of sodium hydroxide has been added to each sample, several of these spot plates are placed in a steam oven. After heating, the

[4]Proper care should be employed in handling these caustic solutions of sodium hydroxide.

plates are removed, held under an ultra-violet light, and the low-coumarin plants detected by their relatively weak fluorescence. Plants corresponding to the low-coumarin samples are retained and analyzed again later by more accurate means. Although results from testing in this manner can only be expressed in such relative terms as "high" and "low", nevertheless it is sufficiently quantitative to to serve as the basis for the selection of non-toxic plants.

FLUOROMETER METHOD

A Coleman photofluorometer No. 12, equipped with B-1 and PC-1 filters, was employed with seemingly excellent results for making quantitative determinations. The samples, including a blank and a standard of known coumarin content, are prepared for examination with the fluorometer by pipetting 1 ml of the solution prepared above into a 100 ml volumetric flask. After diluting with water to the 100 ml mark, about 25 ml are poured into a clean ¾ × 6 inch test tube. The tube and contents are then inserted into the cuvette cavity of the instrument and readings are taken.

A standard of known coumarin content, a blank, and the unknown sweet-clover samples are similarly treated and examined at the same time. The standard can be prepared conveniently by adding 4 mg of pure coumarin to 96 mg of air-dried alfalfa leaves. Setting the meter dial to read 100 for this 4% standard and 0 for the blank (pure alfalfa), the corresponding readings of the unknown samples are made. The meter values for the unknown samples are then converted to coumarin percentages by reference to a curve previously constructed by plotting the fluorometer values obtained from a series of samples of pure coumarin and alfalfa ranging from 0.1% to 40%. Attention should be called to the fact that variations from the stated normality of solution, temperature, and time of heating will change the curve; therefore, these conditions should be the same for the different groups of unknown samples.

PRECISION AND ACCURACY OF FLUOROMETRIC METHOD

The accuracy of the method was tested by the use of increments of pure coumarin added to alfalfa tissue, as well as by the use of mixtures with varying proportions of alfalfa and sweet clover. Results typical of a number of tests in which prepared mixtures of alfalfa and sweet clover were analyzed are given in Table 1. The tables shows good agreement between the percentages of coumarin-bearing sweet clover obtained and the sweet clover content of the mixture as prepared.

A correlation coefficient of +.9895 between duplicate samples was obtained when 100 sweet clover plants were analyzed for coumarin content by means of the fluorometric method.

DISAGREEMENT BETWEEN FLUOROMETRIC AND COLORIMETRIC METHODS

Since the colorimetric method of Clayton and Larmour has been generally used in this country, it was decided to make a comparison of results obtained with the two methods. Table 2 presents a compari-

TABLE 1.—*Measurement of varying quantities of sweet clover in mixtures of alfalfa (coumarin-free) and sweet clover (high coumarin) by means of the fluorometric method of coumarin determination.*

Mixtures as prepared, mg*		Percentage sweet clover found				
		Replication				Average
Sweet clover	Alfalfa	I	II	III	IV	
0	100	0.0	0.0	0.0	0.0	0.0
10	90	10.0	10.0	9.6	9.6	9.8
20	80	20.2	19.8	20.2	20.2	20.1
30	70	28.4	30.1	30.1	29.6	29.5
40	60	40.3	40.3	40.3	39.4	40.1
50	50	50.1	50.5	50.1	50.1	50.2
60	40	60.1	57.4	59.6	57.4	58.6
70	30	69.8	68.6	69.8	69.8	69.5
80	20	79.5	79.1	82.5	80.3	80.4
90	10	89.4	89.0	90.4	87.5	89.1
100	0	100.0	100.0	100.0	100.0	100.0

*The accuracy of weighing was ±0.2 mg.

son of analyses made on one group of samples.[5] These data and others subsequently obtained indicate that the two methods closely agree on ordinary plant material. However, a wide difference in the percentage of coumarin between methods was obtained on such samples as No. 12 (Pioneer) which represent low-coumarin plant selections made at Saskatoon, Canada, by the colorimetric test. The readings obtained by the fluorometric method on such samples are high, while the results

TABLE 2.—*Comparison of analyses of 12 sweet clover samples by means of the Clayton and Larmour colorimetric method and the fluorometric method.*

Sample No.*	Description	Percentage coumarin (air-dried weight)	
		Colorimetric method	Fluorometric method
1	*M. officinalis* 1	0.83	0.60
2	*M. officinalis* 2	0.50	0.53
3	*M. alba* 2	0.46	0.31
4	*M. officinalis* 1A	0.80	0.52
5	*M. officinalis* 8	0.90	0.73
6	GC 82–3 *M. alba*	0.26	0.32
7	*M. alba* 10	0.35	0.37
8	GC 115–1 *M. alba*	0.49	0.35
9	GC 35–5 *M. alba*	0.20	0.20
10	FC 13,275, *M. officinalis*	0.77	0.78
11	*M. dentata*	0.00	0.00
12	J 340(1) Pioneer	0.00	0.73

*Samples 1 to 11 collected October 7, 1943. Sample 12 collected early in the season.

[5]The writers are indebted to Dr. W. K. Smith, Agent, Division of Forage Crops and Diseases, U. S. Dept. of Agriculture, and Assistant Professor, University of Wisconsin, for having these samples analyzed by means of a modified Clayton and Larmour method.

from the colorimetric method indicate an absence of free coumarin. It was thought possible that plant material of this kind contained some other substance which produced fluorescence but which was not detected by the colorimetric test. Subsequent investigations showed that if Pioneer tissue was first extracted with alcohol in the same manner as in the colorimetric test and this alcoholic extract subjected to coumarin analysis with the fluorometric test, low coumarin content was indicated in agreement with results obtained in the colorimetric test. On the other hand, if the Pioneer material was was allowed to stand in water for 24 hours at 27° C previous to the alcoholic extraction, the results would then correspond to those obtained by the fluorometric method without previous hydrolysis and extraction with alcohol. This would suggest the presence of "bound" coumarin or other closely related compound in the Pioneer material which could be released either by enzymatic hydrolysis with water or with sodium hydroxide as in the fluorometric method.

Investigations are now under way at the Nebraska Agricultural Experiment Station to determine the nature and toxicity relations of the bound substance responsible for the higher readings given by the fluorometric method in the instance mentioned.

LITERATURE CITED

1. CLAYTON, J. S., and LARMOUR, R. K. A comparative color test for coumarin and melilotic acid in *Melilotus* species. Can. Jour. Res., 13C:89–100. 1935.
2. PAVOLINI, T. Coumarins and hydroxy-coumarins. Riv. Ital. Essenze Profumi, 8:327–330. 1931. (Chem. Zentr., 1, 1126. 1932.)
3. SMITH, W. K., and BRINK, R. A. Relation of bitterness to the toxic principle in sweetclover. Jour. Agr. Res., 57:145–154. 1938.
4. UFER, MAX. Wege und Ergebnisse der züchterischen Arbeit am Steinklee. Der Züchter, 11/12:255. Nov. 1934.

NOTES

ESTIMATING INDIVIDUAL FORAGE PLANT YIELDS[1]

SINCE increased production is one of the principal objectives in most forage-breeding programs, the plant breeder is concerned with the early evaluation of the productivity of different strains and selections. Plant yields may be taken, but this procedure prevents the accumulation of other notes, such as heading date, seed yield, etc. The taking of yields also requires more time and labor than many research workers have at their disposal. As a solution to these problems an attempt frequently is made to estimate the yields by visual examination, rating the plants from 1 to 5 or 1 to 10 on the basis of the amount of growth present. Often these ratings are made without training and without attempting to determine whether or not the results can be duplicated by another rating.

On May 3 and 4, 1943, individual A tested his ability to consistently rate from 1 to 5 the productivity of 440 spaced plants of Dallis grass, the constituents of a test of 22 strains arranged in four-plant family rows replicated five times. The planting was about 14 months old. Since the plants were similar in type, the rating consisted largely of classifying them into five groups on the basis of their size. They were rated on May 3 and again on May 4 without referring to the May 3 ratings.

A study of these ratings revealed that 63.1% of the plants were given the same rating on May 4 and May 3. Deviations of 1 were found in 35.7% of the cases and deviations of 2 were found in 1.2% of the plants. Deviations larger than 2 did not occur. Although deviations of 1 represent 20% of the total yield range, it should not be concluded that errors of 20% in yield were made in each case where such deviations occurred. In this plant population actual yields would have been so distributed that in better than 40% of the cases ratings of 1.5, 2.5, 3.5, and 4.5 would have been more accurate than ratings of 1.0, 2.0, 3.0, 4.0, and 5.0. It is quite probable, therefore that many of the deviations occurred because the plant in question should have had, for example, an actual yield rating of 2.5 rather than the ratings of 2.0 and 3.0 that it received on consecutive days.

A better evaluation of the yield estimate method may be obtained by taking into consideration the magnitude of all sources of variation in the experiment. The analysis of variance of the yield estimate data (Table 1) shows that the variation attributable to individual A (the mean square for between duplicate ratings of individual plants) is insignificant when compared with the variation associated with the strain test itself. Thus it is evident that the conclusions to be drawn from the strain test would have been altered little, if any, had individual A duplicated each plant rating exactly. It may be concluded from this study that the ability of individual A to duplicate yield

[1]Cooperative investigations at Tifton, Georgia, of the Division of Forage Crops and Diseases, Bureau of Plant Industry, Soils, and Agricultural Engineering, Agricultural Research Administration, U. S. Dept. of Agriculture, the Georgia Coastal Plain Experiment Station, and the Georgia Experiment Station.

estimates of spaced plants is adequate for a strain test of this type where plant size is the principal factor concerned.

TABLE 1.—*Mean squares from the analysis of variance of yield ratings (1 to 5) made on consecutive days on a space-planted Dallis grass strain test.**

Source of variation	D.F.	Mean square
Replications	4	23.15
Strains	21	83.22
Error (A)	84	11.09
Within 4-plant family rows	330	7.38
Date of rating	1	0.70
Between duplicate ratings of individual plants	439	0.40

*A complete set of ratings was made on May 3, 1943, and was repeated on May 4 without reference to the May 3 ratings.

Highly significant differences between Dallis grass strains were established by the yield estimate method (Table 1). Statistical analyses of the green weights of each Dallis grass plant on August 7, 1943, likewise showed the existence of highly significant differences between strains. When the average green weights of these 22 strains were correlated with their average yield ratings, made 2 months earlier, a correlation coefficient of +0.81 was obtained. Since a close correlation between actual yields on May 3 and August 7 would have been expected (judging from past experience), it may be concluded that the yield estimates made on May 3 and 4 would have correlated closely with actual yields made at that time.

On May 21 and 22 an experiment was conducted to determine the value of training in estimating plant yields. A year-old space-planting of Bahia grass was used in which four-plant family rows of 20 strains were arranged in blocks replicated six times. Since these strains differed greatly in density and type of growth, it was extremely difficult to estimate their relative yields. In order to test the ability of different people to estimate the production of these plants, three individuals, each working alone, rated each plant from 1 to 10 before and after training. Individual A, who also made the Dallis grass yield estimates, had had experience estimating the yields of Bahia grass plants but had never checked his estimates with actual yields. Individuals B and C had had no experience nor training in estimating plant yields. The training consisted of checking yield estimates with actual yields of the 80 plants in the first replication. After estimates were made on the remaining five replications, the actual yields of each plant were determined and were used to set up an actual yield classification from 1 to 10. The deviations of the before-training and after-training yield estimates from the actual yield classifications were calculated for each plant and are summarized in Table 2.

It is apparent from Table 2 that each individual reduced the range or magnitude of his deviations (errors) by training. The absolute means included in this table show that each individual overestimated the yield of the average plant, but that each improved noticeably with training. The analysis of variance of these deviations revealed that the individuals differed significantly in their ability to rate the

yield of Bahia grass plants, that their ability was significantly improved after training, and that the individuals differed significantly in their ability to improve with training.

TABLE 2.—*The effect of training upon the ability of three individuals to rate from 1 to 10 the yields of space-planted plants of 20 strains of Bahia grass.*

Person rating plants	Frequency of deviations of estimated from actual yield ratings											Absolute mean deviation
	−6	−5	−4	−3	−2	−1	0	+1	+2	+3	+4	
Individual A:												
Before training	1	1	14	47	71	94	94	37	22	4	1	−0.899
After training..	–	–	—	4	36	77	155	82	25	5	1	−0.026
Individual B:												
Before training	1	1	19	75	88	67	79	23	24	7	4	−1.153
After training..	–	–	—	6	45	115	152	41	19	6	3	−0.294
Individual C:												
Before training	–	2	25	70	82	69	63	43	17	2	–	−1.260
After training..	–	–	—	18	80	87	119	38	24	6	–	−0.530

Statistical analyses of the actual yield ratings showed that the 20 strains of Bahia grass ranged from 2.1 to 7.8 in mean yield and gave a least significant 5% difference for strain means of 1.17. An appraisal of the usefulness of the yield estimate method may be made by comparing the strain means obtained from the yield estimates of individuals A, B, and C with the actual mean rating of each strain. The least significant mean difference of the actual yield ratings, 1.17, was used to determine which strains each individual placed in a yield group significantly different from its actual yield group. Following this procedure, it was found that before training, A misplaced 7 strains, B 12 strains, and C 12 strains. After training, A and B placed each of the 20 strains in its proper yield group and C misplaced only four of them.

It was most encouraging to discover that individuals B and C with no experience nor training could, after a short training period, estimate so closely the mean yields of these variable Bahia grass strains. Since individuals A, B, and C differed significantly in their ability to rate these plants, it seems quite probable that some individuals might be able to estimate plant yields with even greater accuracy, while others might never be able to reach the desired level of precision. The value of a short training period in which yield estimates are compared with actual yields has been well demonstrated. Such training might be considered a prerequisite when the material to be rated differs greatly in density and type of growth.

Table 2 shows that even after training, the individuals who made these ratings placed only 40% or less of the plants in their proper yield groups. Yet the mean of the estimated ratings given the 18 to 20 plants of each strain deviated from the mean of the actual yield ratings by more than one class unit in only seven cases for C, two cases

for B, and none for A. It is apparent, therefore, that in many cases positive deviations compensated for negative deviations. Evidently, greater precision in the estimation of single plant yields could have been achieved by repeating several times the entire set of ratings.

Where a reasonably precise yield rating of individual plants is desired, it will probably be necessary to repeat several times the ratings made for any particular planting. However, where the main emphasis is upon the mean yield rating of a strain represented by a number of plants, one rating may be adequate.—GLENN W. BURTON, *Coastal Plain Experiment Station, Tifton, Ga.*

COMMENT ON "WHAT IT TAKES TO TEACH THE PLANT SCIENCES"

A RECENT article[1] in this JOURNAL reports the results of a study in which some 1,100 professional workers in the plant sciences rated "as objectively as possible, the teachers who had most influenced them in the field of plant science, or seemed the most influential in their undergraduate or graduate careers." These specialists all used the Purdue rating scale for instructors, which asks the person making the rating to indicate for each of ten qualities the point on the scale "which most nearly describes" the teacher being rated. Thus, each characteristic is considered separately *without reference to the others*. Moreover, the scale indicates that the rating for any one characteristic is to be made with reference to the student's ideal conception of that same quality and that the rating is to represent the *extent of the teacher's approach (to) this ideal.*"

In an analogous situation each one of a large number of judges might be asked to select the best sample of wheat which he has seen during the past two years and to rate it by means of a score card. This instrument would list a number of factors such as test weight per bushel, absence of damaged kernels, hardness, plumpness, odor, etc., each factor being assigned a perfect score of, let us say, 100. Let us assume that the average ratings for all of the samples is 90 in plumpness and 80 in hardness. Obviously, it does not follow that the former factor is, therefore, *necessarily* more important than the latter, that plumpness is more to be desired than hardness. The results merely indicate that the samples were more nearly perfect in the former respect than in the latter, in the opinion of the judges.

The article under consideration draws the following conclusion from the data relative to the ratings of the teachers: The fact that "certain characteristics were rated much lower than others seems to indicate that they were less important." Although this conclusion is presented very guardedly, it bears close examination. The present writer does not wish in any sense to contradict this statement—his contention is simply that the study was not designed to throw light upon the matter.

In view of the instructions for the use of the Purdue scale which have already been cited, the data reported in the article merely indicate how far the teachers rated had advanced toward the ideal

[1]STEVENS, NEIL E. What it takes to teach the plant sciences. Jour. Amer. Soc. Agron., 36:316–323. 1944.

with respect to each of the ten traits included in this instrument. The results give no *direct* measure of the relative importance of these traits since the use of the scale does not involve making any comparisons among them. The article in question apparently admits this fact, but it states that *indirectly* the data seem to be indicative of the comparative importance of these traits. It should be noted, however, that even an "influential" teacher is not necessarily perfect, and that he might be even more successful if he were deserving of a higher rating, with respect to any given characteristic, than he actually receives. A person who assigns him a relatively low rating in any trait may, in fact, even be definitely dissatisfied with him *in that respect*. But the returns from the Purdue scale provide no information on this point; consequently, it is just as plausible to argue that a teacher rated by means of this device failed to realize his highest potential success *because* of a certain deficiency as it is to contend that he attained his actual success *despite* that same deficiency.

The fact that a large number of college instructors all tended to rate relatively low (or high) in the same trait may be simply a reflection of the level of esteem in which subject matter specialists in higher institutions have generally, whether rightly or wrongly, held this characteristic. This fact may explain the finding that "those elements which have to do with teaching as teaching occupy at best but an intermediate place." If this finding is generally applicable to college teachers in a given field, then even those picked as the "most influential" can probably be only intermediate in these same elements since there is hardly anyone else to choose. They will be selected because of outstandingness in other respects, but their comparatively mediocre traits are likely to be reflected in the ratings returned by their students.—EDWARD F. POTTHOFF, *Univ. of Illinois, Urbana, Ill.*

BOOK REVIEWS

INORGANIC NUTRITION OF PLANTS

By D. R. Hoagland. Waltham, Mass.: The Chronica Botanica Co.; New York: G. E. Stechert and Co. IX+226 pages, illus. 1944. $4.

THIS book records the seven Prather Lectures given at Harvard University on the subject of the inorganic nutrition of plants. The lectures cover, respectively, the following topics: A survey of problems of plant nutrition; micronutrient chemical elements and plant growth; the absorption and accumulation of salts by plant cells; upward movement and distribution of inorganic solutes in the plant; the growth of plants in artificial media in relation to the study of plant nutrition; some biochemical problems associated with salt absorption; and aspects of the potassium nutrition of plants as illustrating problems of the system, soil-plant-atmosphere. Twenty-eight excellent illustrations of experimental technics and results are included.

The purpose of the author seems to have been to present a broad view of the many interrelationships involved in plant nutrition, to emphasize the importance of new and coordinated approaches to the

problems involved, and to stimulate the interest of the reader. These purposes are achieved in a very satisfactory manner.

The book is written in a very readible style. The author draws heavily on the many important investigations conducted on the general subject by himself and coworkers. The advanced student may wish that the author had made a more exhaustive coverage of the subject and provided a more complete bibliography, but this was not the purpose of the lectures.

The book will be of inestimable value to all students of the plant sciences, whether or not they are specialists in the field of plant nutrition.—W. H. PIERRE.

THE PEATS OF NEW JERSEY AND THEIR UTILIZATION

By Selman A Waksman, H. Schulhoff, C. A. Heckman, T. C. Cordon, and S. C. Stevens, Trenton, N. J.: Department of Conservation and Development, State of New Jersey. Bulletin 55, Part B. 278 pages, illus. 1944. $1.

BY THE publication of this bulletin, the survey of the peat deposits of New Jersey, undertaken as official project No. 65-1-22-477 of the Works Project Administration, has been completed. Part A, published in 1942, was sub-titled, "Nature and origin of peat: Composition and utilization". Part B gives detailed information obtained by a careful field survey of the peat bogs of the state.

Data are given on depth of deposits, nature of the plant material, and its chemical composition. Three broad regions are recognized, *viz.*, the sedge and reed peats to the north; the forest peats, characterized by cedar swamps, on the coastal plain; and the salt marsh and alluvial peats. No true sphagnum peats were found. Some 200,000 acres of true peat were surveyed.

The bulletin is of general interest to all those concerned with the study or utilization of peat deposits and of special interest to the farmers of New Jersey's peat deposits, or to those located nearby on whose farms hauled-in peat could possibly be used to advantage. An extended bibliography of 110 titles is appended. Bulletin 55, in its entirety, represents a monumental contribution on this interesting and important subject, of great interest and value both currently and permanently.—FIRMAN E. BEAR.

AGRONOMIC AFFAIRS

PROCEEDINGS OF NATIONAL JOINT COMMITTEE ON FERTILIZER APPLICATION

THE PROCEEDINGS of the nineteenth annual meeting of the National Joint Committee on Fertilizer Application, held at Cincinnati, Ohio, November 9, 1943, has been published and distributed by the National Fertilizer Association. In addition to the reports of the cooperators, a review is presented showing the scope and distribution of fertilizer application experiments conducted in 1943, with special

reports for the Northeast and the West. A report of a special committee on fundamental problems of fertilizer application is also included.

Special papers presented at the meeting and included in the proceedings are as follows: "Distribution of Various Types of Ammonium Nitrate", by G. A. Cumings, L. G. Schoenleber, and C. W. Whittaker; "The Influence of Placement on the Efficiency of Different Calcium Phosphates in Greenhouse Experiments", by Dana G. Coe, R. P. Bartholomew, G. W. Volk, and C. W. Whittaker; "The Distribution of Nitrogen Materials in Irrigation Water", by H. D. Chapman; "The Distribution of Nitrogen Fertilizers in Solution", by F. W. Parker; and "Principles Determining Where Fertilizers Should be Placed for Greatest Efficiency", by Ralph W. Cummings.

Organizations represented on the Committee include the American Society of Agricultural Engineers, the American Society of Agronomy, the American Society for Horticultural Science, the Farm Equipment Institute, and the National Fertilizer Association. Officers of the Joint Committee for 1944 were elected as follows: E. R. Collins, Raleigh, N. C., General Chairman; S. D. Gray, Washington, D. C., General Vice Chairman; and H. R. Smalley, General Secretary. A number of sub-committees and special committees for 1944 were named and are listed in the proceedings.

BIBLIOGRAPHY ON MINOR ELEMENTS

THE CHILEAN NITRATE EDUCATIONAL BUREAU, INC., 120 Broadway, New York, announces the publication of the fifth supplement to the third edition of its "Bibliography of References to the Literature on the Minor Elements and Their Relation to Plant and Animal Nutrition". The supplement contains 722 abstracts, which include 117 crops and 40 elements. There are 919 authors listed and four complete indices are provided, including an element index, a botanical index, an author index, and for the first time, an index to abstracts dealing with animal nutrition.

"BORON AND PLANT LIFE, V"

THE AMERICAN POTASH INSTITUTE, INC., 1155 Sixteenth Street, N. W., Washington 6, D. C., announces the availability of a limited number of reprints of the latest in the series of reviews on the role of boron in plant nutrition prepared by A. C. Dennis and R. W. G. Dennis. The appended bibliography includes 186 titles.

NEWS ITEMS

THE WAR FOOD ADMINISTRATION, in a recent release, forecast that potash supplies for 1944–45 would be 21% more than in 1943–44, indicating a total of 731,000 tons of K_2O for agricultural use in 1944–45. According to the American Potash Institute, in addition to this unprecedented tonnage for agricultural use within the United States, Canadian requirements of 46,000 tons of K_2O are being supplied, the American chemical industry is being allocated 100,000 tons, and

additional tonnages are being set aside for export, representing a noteworthy achievement in potash production under war conditions.

—A—

FROM THE UNIVERSITY OF FLORIDA comes word that Dr. R. V. Allison has been designated Vice Director, in charge, the Everglades Experiment Station at Belle Glade; that Dr. J. R. Neller has been appointed Soils Biochemist at the main Experiment Station at Gainesville; and that Dr. F. B. Smith has been named Acting Head of the Department of Soils at the main Station.

—A—

DR. A. L. GRIZZARD, who left the Virginia Agricultural Experiment Station in April 1943 to accept a position as Agronomist with the Office of Inter-American Affairs in El Salvador, returned to this country to accept a position as Agronomist with the Smith Douglas Fertilizer Company, Norfolk, Virginia, beginning May 1, 1944.

—A—

J. KENNETH ABLEITER, Principal Soil Scientist of the Division of Soil Survey, U. S. Dept. of Agriculture, has been appointed Chief Inspector. In this position he is responsible for the system of soil classification, including the definition and nomenclature of the units of classification, and of soils inspection. Formerly he was in charge of the Division's work on soil uses and productivity; and he has been Acting Chief Inspector since the recent retirement of Dr. Mark Baldwin from the federal service.

—A—

DR. CARLETON P. BARNES, Principal Soil Scientist of the Division of Soil Survey, U. S. Dept. of Agriculture, has been appointed Chief Analyst, Soil Uses and Productivity, the position formerly occupied by J. K. Ableiter. In this position he is responsible for the interpretation of soil classification and soil maps in terms of productivity, crop adaptability, management requirements, and potentialities for use. Over 10 years ago Dr. Barnes worked with Dr. Marbut in developing a system of rating soil types according to productivity. Since then he has been working on important problems of land classification and land-use planning in the Department. Previous to his recent transfer to this Bureau, Dr. Barnes was Associate Land Use Coordinator in the Office of the Secretary.

—A—

DR. G. DONALD SHERMAN, formerly Assistant Chemist in the Southern Regional Research Laboratory at New Orleans, La., has been appointed Station Chemist and Head of the Chemistry Department of the Hawaii Agricultural Experiment Station at Honolulu, and has entered upon his new duties.

JOURNAL

OF THE

American Society of Agronomy

VOL. 36 SEPTEMBER, 1944 NO. 9

CROP IMPROVEMENT, A WEAPON OF WAR AND AN INSTRUMENT OF PEACE[1]

M. A. McCALL[2]

WE ARE now in the third year of war. We are confident of ultimate victory. We are still uncertain about what is required to get the kind of peace we want, but we are not uncertain about the important role which crop agriculture must play both in winning the war and in determining how successful final peace can be.

Immediately after Pearl Harbor, Secretary Wickard indirectly indicated our part in the war as agronomists when he said, "Food will win the war and write the peace." President Roosevelt, in his special message on food delivered to the Congress in early November 1943, again emphasized and further amplified the role of food in war in such a way as to point up our part as agronomists in the over-all program. The President said,

"Food is as important as any other weapon in the successful prosecution of the war. It will be equally important in rehabilitation and relief in the liberated areas, and in the shaping of the peace that is to come.

"The first major objective of our food program is to raise in the most efficient manner enough food and the right kinds of food to meet our needs."

The emphasis placed by the President on efficiency of production not only carried a direct challenge to all concerned, but specifically indicated our primary responsibility.

The American farmer has done an outstanding job in meeting the challenge to produce food. His achievements have been phenomenal considering the handicaps of labor shortage and insufficient equipment. He has been indeed efficient.

No one would wish to take any credit from our farmers for the truly magnificent contribution they have made to the war effort. The agronomists of our country, however, also must be given substantial

[1]Presented as part of a symposium on "Agronomic Contributions and Their Current Significance" at the annual meeting of the American Society of Agronomy held in Cincinnati, Ohio, Nov. 11–12, 1943. Received for publication April 21, 1944.

[2]Head Agronomist, in Charge, Division of Cereal Crops and Diseases, and Assistant Chief, Bureau of Plant Industry, Soils, and Agricultural Engineering, Agricultural Research Administration, U. S. Dept. of Agriculture.

credit for having helped to make possible the farmer's achievement. This fact is not always too clear to the general public. Nor is it always too clear to agronomists themselves. Particularly among our younger colleagues, there has been evident a feeling of unrest and uncertainty as to the relative importance of what we have been contributing as individuals to the war effort, and as to whether or not we have been carrying our proper load of responsibility.

In case of uncertainty it is always well to take a look at the record. A look at the record and at least a partial survey of the job to be done during the war period and immediately after should give a better perspective and help each of us to determine where he can make his most effective individual contribution.

"Food" and "food production" in the sense used by Secretary Wickard and President Roosevelt are inclusive terms, meaning any crop or product that directly or indirectly contributes to ultimate food supplies. Even crops not used for food or feed, but necessary for the war effort or for the welfare of our people are properly classed in the same category, examples being cotton and other fiber crops and tobacco.

It is impossible to cover all contributions of field crop research to the war effort within the proper limits of this discussion. For that reason we will consider only selected high lights that could be multiplied almost without end. Similarly, in surveying the job to be done, there will be no attempt to be all inclusive.

HYBRID CORN

Corn contributes more to our total wartime food supply than any other crop. The 1942 corn crop totaling 3,175,000,000 bushels was the largest of record. The 1943 crop is estimated at 3,085,000,000 bushels, the second largest of record. Never before have we grown 3,000,000,000 bushels in two successive years. The 1942 crop was grown on 89,484,000 acres, the 1943 crop on 94,308,000 acres, and the 1920 crop, 3,070,000,000 bushels, the third largest of record, on 101,359,000 acres. Hybrid corn is responsible for this result. The cooperative research of the state agricultural experiment stations and the Bureau of Plant Industry, Soils, and Agricultural Engineering is responsible for hybrid corn.

It is not easy to determine exactly how much hybrid corn does contribute in increased production. In 1942 the Division of Crop Estimates of the Bureau of Agricultural Economics estimated the increased yield from hybrid corn as 300,000,000 bushels. This figure is roughly an increase of 7.5 bushels for each acre of hybrid corn grown in 1942. This estimate of increase was based on estimates of farmer reporters, a large proportion of whom did not have open-pollinated corn against which to make comparisons. Considering average state yields during the long-time period of open-pollinated corn production this estimated increase seems too low.

Dr. Merle T. Jenkins and the writer, therefore, undertook to arrive at what might be a more nearly correct figure. There are available in the several states comparative yields for hybrids and open-pollinated

varieties, which might be expected to give a good basis for determining relative yields. On the other hand, these comparisons are not made with the average farmer's open-pollinated seed, but with the very best open-pollinated strains. It would seem, therefore, that these tests also might give too low a figure so far as farm production is concerned.

Another way is to compare the average yield for the past 6 years in those states in which hybrid corn predominates with the average in those same states for a base period before hybrid corn came into the picture. The acreage of hybrid corn of course must be taken into account and a base period must be chosen with similar conditions, if the comparison is to be completely valid. The period 1923–32 was finally chosen. It is the last 10-year period immediately preceding hybrid corn production which is not too seriously affected by drought, and it seems to be not too far from the average in general conditions, although it does include the dry year of 1930. Soil conditions also were more nearly the same as during the period of hybrid corn.

Each year for the period of 1938 to 1943, inclusive, 50% or more of the corn acreage in each of the five states of Iowa, Illinois, Ohio, Indiana, and Minnesota was planted to hybrids each year. During this period these states produced 8,815,067,000 bushels of corn. The same acreage on the basis of the 1923–32 average yields would have produced 6,421,670,000 bushels, or an increase of 2,393,397,000 bushels. Attributing this increase to hybrid corn, each acre of the 132,487,000 acres of hybrid corn grown in these five states, during the 6 years, gave an average increased yield of 18.1 bushels.

In 1943 the hybrid corn acreage of these same five states was 31,200,000 acres. Assuming the 6-year average increase per acre from growing the hybrids, the total increased yield in 1943 was 564,720,000 bushels. Assuming only one-third as great an increase on the remaining 17,460,000 acres of hybrid corn grown in the United States in 1943 gives an additional 104,760,000 bushels, or a total increase from hybrid corn in 1943 of 669,480,000 bushels. While this is an astounding figure, it seems reasonable.

Incidentally, in terms of meat, the estimated increased yield from hybrid corn is equivalent to 7,364,280,000 pounds of pork. This is 54 pounds of meat for each man, woman, and child in the United States. Also, it is more than three-fourths the total meat required for our armed forces and Lend-Lease.

DISEASE-RESISTANT OATS

Another most significant development playing a major role in the efficiency of wartime crop production has been the distribution of the new smut and crown and stem-rust resistant oat varieties, Vicland, Cedar, Tama, Boone, Vikota, Control, and Marion. Farmers have had full opportunity to see these varieties perform during the 1942 and 1943 crop years. There is every reason to believe that from 80 to 90% or more of the acreage in Iowa and Wisconsin, and a considerable acreage in adjoining states will be sown to them in 1944. In experimental tests and on farms these varieties yield from 10 to 25 bushels or more above the varieties they are replacing when rust is a factor,

and even in non-rust years they are as good or better. In Wisconsin and Iowa where these new varieties occupied a substantial part of the total acreage in 1943, average yields were substantially better than in neighboring states.

Estimating 10,000,000 acres as planted to these varieties during each of the next 2 years and a very conservative average farm increase of only 7.5 bushels per acre, we can expect an added annual production of at least 75,000,000 bushels of this valuable feed grain for the war period. Or putting the matter another way, this amount of added production will allow the release of at least 2,500,000 acres for growing other emergency war crops without a decrease in oat production.

SOYBEANS

The critical wartime fat and oil situation has given added pressure for soybean production. In 1941 the acreage harvested for soybeans was 5,855,000 acres; in 1942, 10,008,000 acres; in 1943, 10,820,000 acres; and a 1944 goal of more than 13,000,000 acres was requested. The increase in the production of this crop as a wartime necessity has been remarkable. It has been possible only because of the new varieties which have been developed in the cooperative program of the states and the federal Department of Agriculture. Newly introduced varieties which mature satisfactorily in the several areas yet utilize the full growing season, and have a higher oil content than those previously available, have been a contribution to our war economy hard to overvalue. The more than 13,000,000 acres requested for 1944, estimated to produce 17.3 bushels per acre, if attained, should give approximately 225,000,000 bushels of soybeans of which 160,000,000 bushels should be available for crushing. This should produce 1.4 billion pounds of oil, roughly three fourths of our prewar annual fat imports.

RUST-RESISTANT WHEAT

The crop year of 1935 from a weather standpoint was one of the most favorable in the hard red spring wheat belt in recent years. Early in the season the prospects for a bumper wheat crop were bright. Then the picture changed and stem rust swept the area. In Minnesota and the two Dakotas there were produced only 72,000,000 bushels of wheat on 10,000,000 acres. The new stem-rust resistant variety Thatcher had just been released to farmers in 1934, and its record under epidemic conditions put it across. The seasons of 1937 and 1938 were also stem-rust epidemic years, and by 1939 Thatcher had almost pushed out the susceptible Marquis and Ceres, not only in the United States, but also in Canada. It was estimated that 13.5 million acres were grown in that year, which in the next 2 years increased to 18,000,000 acres. Thatcher proved susceptible to leaf rust, however, and in 1941 and 1942 was seriously damaged by that disease. In the meantime, the varieties Rival and Pilot, produced in cooperative research in North Dakota, had been released. They possessed resistance not only to stem rust, but also to leaf rust. As a result they have been replacing Thatcher in much of the area where leaf rust has been important.

In 1942 the few scattering fields of susceptible Marquis which remained were again badly damaged by stem rust, conditions in general suggesting a situation not unlike 1935, except for the presence of resistant varieties. The acreage of Rival, Pilot, and other similar rust-resistant varieties was not injured by either leaf or stem rust, and while the Thatcher acreage was injured by leaf rust, this damage was not comparable to stem rust damage on susceptible Marquis. As a result the three states produced 166,000,000 bushels of hard red spring wheat on 8,600,000 acres. Comparing this yield and relative acreage with the 1935 result, it seems a safe assumption that because of the stem rust-resistant varieties some 100,000,000 additional bushels of hard red spring wheat were harvested in this area in 1942. Incidentally, 1943, has been another fairly good year in that region, the three states producing 160,734,000 bushels of hard red spring wheat on 9,394,000 acres. Some reduction in yield occurred from scab and leaf rust, but there was no significant reduction from stem rust.

In the Pacific Northwest bunt was formerly a most serious hazard in wheat growing. In 1914, over 300 threshing machine separators exploded and burned up in eastern Washington alone. Infection ran as high as 50 and 75% in entire fields in many cases. Such heavy infections produced a comparable reduction in yield, in addition to the other losses attendant on high smut infection. Soil infestation made control by seed treatment impossible. With the breeding and introduction of bunt-resistant varieties the picture has entirely changed. In 1931–32, 36.7% of all carload receipts at Spokane, Columbia River, and Puget Sound terminal markets graded smutty. Five years later in 1936–37, 16.7% graded smutty. In 1942–43, only 2.3% graded smutty. This gradual change paints the story of the production and use of smut-resistant varieties.

COTTON

Another activity of a somewhat different nature than crop improvement itself, yet an integral part of the crop improvement program, is the single cotton variety community project in the southern states. In 1942 there were 2,563 one-variety communities operating in 575 counties in 17 cotton-producing states, and involving 7,613,533 acres and a production of 4,570, 122 bales. This was 35% of the total cotton crop, and a considerably higher proportion of that part of the crop most needed to supply standard materials for the Army and Navy. Research has demonstrated that yarns from the varieties chosen for growing in the single-variety communities are from 15 to 20% stronger than produced from most of the other widely grown varieties of equal length. The importance of this large supply of superior cotton during the war emergency cannot be overestimated.

Among other urgent needs of the armed forces have been adequate supplies of long staple cottons of superior strength for special uses. The presently grown variety of American-Egyptian, SXP, has been demonstrated to possess the necessary values to meet special requirements for balloon cloth, life preservers and rafts, machine gun webbings, and many other critical uses for which strength and wearing

quality are necessary. A new variety, Amsak, just coming into production is equal or even superior to the best Egyptian varieties formerly standard for such specialties. Farmers have beeen able to meet this critical need only because of these superior varieties.

Instance after instance of similar direct import to the Nation's war production program could easily be cited for all of our standard crops. Improved alfalfas, red clovers, sweet clovers, grasses, sugar crops, fiber crops, all are playing a direct and vital role in increasing the efficiency of wartime production. Anyone concerned in their development and use, therefore, has made a most important contribution to the war effort.

CURRENT PROBLEMS

Objection might be raised that the job so far as wartime production is concerned was already done, and that the crop breeder could not make a currently significant contribution to the war effort. That view does not seem to be correct. The hybrid corn breeders of the cooperative state and federal program are making a direct current contribution to national corn production. Probably one-half the total hybrid corn acreage depends on seed stocks produced by relatively small growers, who in turn look to the cooperative program for their foundation seed. Provision has been made for adequate reserves of these foundation stocks so as to prevent any serious shortage in case of a major weather or other production hazard. This is certainly a vital job. Other crop breeders are likewise giving special attention to increasing and distributing seed of improved varieties most likely to increase production efficiency.

No variety or strain, no matter how much superior to previously existing varieties is entirely without fault, some of which may offer hazards to maximum possibilities during the war. During such a critical period, there is added reason for carefully scanning and evaluating new materials of promise which are nearing the end of predistribution tests. If they possess attributes reducing production risks, there is every reason to increase them for immediate farm use. In line with this policy, 35 new crop varieties were distributed during the current season from the cooperative breeding projects of the state stations and the Bureau of Plant Industry, Soils, and Agricultural Engineering. Twenty-one of these new varieties were field crops: 9 wheat, 2 rice, 2 flax, 2 cotton, 1 alfalfa, 2 soybean, 1 sugar cane, 2 tobacco. While not yet in largest quantity production, these new contributions can be expected to make an immediate addition to wartime cropping efficiency. In one county in North Carolina, for example, the county agent estimates that new tabacco varieties just released, because of their resistance to root rot and black shank, added $200,000 to the income of his farmers in 1943. This means at least $400,000 in added income to the federal government in tobacco taxes. It is almost certain that other new varieties will make similar contributions before the war ends. Nor is there reason to believe that these are the only new and significant results that may be forthcoming from our cooperative efforts during the war period.

Emergency problems are constantly arising, in part because of the pressures due to wartime conditions. New crops, new expansions of old

crops, acute hazards of one kind and another, require constant attention in order to protect and safeguard production. One of the most important functions of all crop specialists during the emergency is that of preventing or avoiding threatened hazards through constant vigilance and anticipation of problems insofar as possible. Now is the time, above all others, to be on the lookout for new diseases, new races of prevalent diseases, new soil and other problems, and to accumulate information and resistant breeding stocks, so as to meet each and every possible contingency as it may arise as quickly as possible and with a minimum of disturbance. Insufficient labor and assistance add to the difficulties of doing the best job, but these are the same limitations that beset the farmer in his part of the program. Certainly we can go as far as the farmer has gone under such handicaps and can do an equally good job.

The spread of the corn borer into the Corn Belt has introduced a new menace to wartime corn growing. This is an example of an emergency problem calling for the best effort of our corn breeders. While available resistant materials are not all that we might desire, a great deal can be done and is being done to meet the situation. The importance of such wartime service cannot be questioned.

It may be easy to overlook one phase of our responsibility under the pressure of the present emergency. The breeding work upon which the efficiency of current production depends was begun, much of it, 20 or 25 years ago. Similarly, the advances of 10, 15, or 20 years from now are dependent on groundwork that we may be laying now, or at least are holding ready for active work at the earliest possible moment. While of course it is essential that we give our major effort to problems directly contributing to expediting the war program, we should, also, insofar as we can, give at least some thought to the long-time angle of the over-all problem. Plans should be laid now for more intensive and extended undertakings after the war.

FUNDAMENTAL RESEARCH NEEDED

In particular we should bear in mind that future progress is not possible without research in the basic sciences on which improvement depends. Our present advances and accomplishments in producing hybrid corn are directly the outcome of fundamental research in genetics. Future advances and improvements in corn breeding depend on further advances in genetic information. One of our greatest handicaps in breeding the small grains has been a too limited knowledge of the genetics of these crop plants. Fortunately, there is now opening up a new opportunity for advancement in that field. Sears, in cooperative work at the Missouri Experiment Station on the polyploid genetics of wheat, has isolated monosomic and nullisomic lines which through appropriate crosses, give an opportunity to locate and identify genes in a way not heretofore possible. These technics also promise an easier method for adding genes to the wheat complement from related species and genera. Nullisomic cultures have been isolated which involve 17 of the 21 chromosomes of the *Triticum vulgare* complement, and there is every hope that eventually nullisomes for each of the 21 will be obtained. Already certain genes have been

located on definite chromosomes by the nullisomic technic, and ultimately it should be possible to obtain a genic analysis for polyploid wheat comparable with that now available for corn. Nullisomes have been reported for oats, although nothing comparable to Sears' work with wheat has been undertaken with this species. The possibility of using the technic in oat genetics, however, would seem to be equally good. There also should be equal opportunities with other self-fertilized polyploid species as well. We should be planning future work to utilize these new tools.

One of the most important obligations facing the plant breeder is to protect improvements already made. This is particularly true in the case of disease-resistant varieties. The increase and widespread distribution of physiologic races of disease organisms to which the heretofore resistant variety may be susceptible can nullify the advance insofar as farm production is concerned. This has already happened in the past with some of our stem-rust resistant wheats, and there is every reason to believe it can and will happen again. It behooves us, therefore, to be constantly on the alert for the appearance and spread of new races of stem rust, and to locate and have available materials resistant to these races insofar as we possibly can. One of the major tasks which should be pushed to the limit is the location of as many kinds of resistance to rust from as many sources as we can find, and the transfer of these to usable stocks for immediate use in breeding operations. The genetic analysis of these different kinds of genic resistance should be considered an essential part of the program. The ultimate designation of the pathogenic races of various diseases, particularly the smuts and rusts, should be based on such definite genetic analyses. Host differentials should be determined by genetic constitution, and not by emperical test. Such a program will require the closest possible cooperation between the plant geneticist and the plant pathologist. The nullisomic technic gives an opportunity to do this kind of a job in the case of wheat and oats.

In the southern United States, one of the most important tasks ahead of us is to breed small grain varieties more resistant to disease and winterkilling than anything yet available. These crops offer great possibilities for producing grain feed and fall, winter, and spring pasture, at the same time giving adequate soil cover for preventing erosion, provided disease and winterkilling can be conquered. The solution of the disease problem seems to be in sight. The winter-killing problem offers more difficulty. There seems to be some promise, however, in combining the best dormancy cold resistance with greater cold resistance in the growing condition. There are varieties, particularly of oats and barley, which grow and mature seed on the high mountain slopes of central Asia where they are subjected to frost throughout the season. This type of cold resistance added to what we already have might materially increase the certainty of survival in the South and also add to the winter pasture value of varieties for that area. Conceivably such a combination also could extend the northern limits of winter oat and barley growing.

Another important task that lies ahead of us is the collection of as complete a sample of world germ plasm for our several crop plants as

we can get. This then should be analyzed to determine where we can turn to get such characters as we may need in our breeding program. The existing collections of the Department of Agriculture for the various crops are already extensive, but they by no means represent all that may be available in germ plasm values. Nor have they been adequately analyzed to determine all the values that even they may contain. One of our biggest postwar jobs is to embark on an extensive program of crop plant exploration, and to analyze such new materials and our present collections as fully as possible.

Obviously, in a general discussion, it is impossible to more than touch on a few of the many crop-breeding problems that should receive attention in a wartime and in a postwar program. Our present knowledge is too incomplete to know all that should be done. Many problems arise as unforseen emergencies. Others come into being because of economic conditions. Even such things as labor legislation may have an effect. The Wages and Hours Law because of its provisions on hours of work and overtime pay has had an effect on the kind of flour commercial bakers now want. This can conceivably have a profound effect on future standards for quality in bread wheats. Similarly, new information on nutrition may change our ideas on what we desire in a given crop, and may even introduce new factors into our breeding concepts. Changes in cropping systems, as for example the extensive introduction of grass and legume pastures into standard rotations, may entirely change requirements in grain and other crops and so modify breeding objectives. Large supplies of relatively cheap agricultural nitrogen after the war certainly will have its effect, which we should even now be attempting to determine. Added to the multitude of problems of this nature are, of course, the constantly arising difficulties we have always had with us in one form or another and which must be met as they come. The Helminthosporium leaf blight and Stewart's wilt on field corn are examples. And so the list could be extended.

Looking again at the record, and judging the future by the past, I have complete confidence that present accomplishments are only a beginning in the ultimate results to be expected from our American crop breeders. They now deserve the nation's gratitude for their contribution in her hour of need. And when the war is done may the sword now being used so effectively on the field of Armageddon again become a plowshare delving in the plains of Sharon.

INHIBITORY PLANT GROWTH FACTORS IN PARTIALLY STERILIZED SOILS[1]

R. R. ROBINSON[2]

ALTHOUGH steam sterilization of soils is widely used for the control of plant diseases, sterilization may have a deleterious effect on subsequent plant growth. The literature (1, 2, 3, 4, 5, 6, 10, 11, 14, 15)[3] indicates that the nature and extent of plant injury varies with the soil, the temperature and the duration of sterilization, the species of plant, and various undetermined factors. Symptoms of injury may be expressed as retardation in growth, purple pigmentation, and mottled or necrotic leaves. In some cases a high percentage of the plants die. The injury may be temporary or last several months. Sometimes seed germination is inhibited but plant growth is normal, whereas in other cases seed germination is normal but plant growth is inhibited. Hoffman (1) reported that transplanted plants may grow rapidly for a time and then suddenly show injury.

The objective of the present investigation was to determine the conditions under which injury occurred, the possible cause of the injury, and the methods for preventing or overcoming it.

SOILS USED IN THE EXPERIMENT

The soils used (Table 1) were all low in available phosphorus but differed widely in other respects.[4] Hagerstown soil and subsoil were obtained from a plot in the Jordan Fertility Series that in previous years had received lime, potash, and nitrogen, but no phosphate. Dekalb soil and subsoil were obtained from a rundown pasture which probably had never been limed or fertilized. In order to study the effects of soil reaction on the results obtained, the Dekalb soil was separated into three portions. One portion (pH 4.9) was untreated, another limed to pH 6.1, and a third limed to pH 5.6 after the heat treatment. All three portions were stored in the open for 1 year prior to being used in the tests. Both the Hagerstown and the Dekalb soils were mixed with sand at the ratio of two parts of soil to one part of sand. The subsoils were mixed with equal parts of sand.

GENERAL PROCEDURE

Phosphate was applied at different rates as monocalcium phosphate ground to pass a 40-mesh screen and was thoroughly mixed with the soil prior to the heat treatment, except where otherwise noted. The rates were calculated on the basis of the soil exclusive of any sand added. Except as indicated, the soils were maintained at about optimum moisture content during the temperature treatments. Where legumes were used as the test crop the soil was inoculated with a culture of rhizobium at the time the crop was planted. During the winter, Mazda lamps supplied light at an intensity of about 75 foot candles to increase the day length to 13 hours.

[1]Contribution No. 57, of the U. S. Regional Pasture Research Laboratory, Division of Forage Crops and Diseases, Bureau of Plant Industry, Soils, and Agricultural Engineering, Agricultural Research Administration, U. S. Dept. of Agriculture, State College, Pa., in cooperation with the northeastern states. Received for publication December 13, 1943.

[2]Associate Agronomist.

[3]Figures in parenthesis refer to "Literature Cited", p. 738.

[4]The writer wishes to express his appreciation to Professor J. W. White of The Pennsylvania State College for permission to obtain samples of soil from the Jordan Fertility Plots, and to J. D. Warner of the Florida Agricultural Experiment Station for supplying a sample of Orangeburg soil.

In the trials reported in Table 1, nine young seedlings of Ladino clover were transplanted to the pots and the crop was clipped at the end of 10 weeks to a height of 1½ inches. In subsequent trials the test crop was seeded following the temperature treatment and later thinned to seven plants per pot for Ladino clover or two plants per pot for crops such as corn, tomatoes, and barley. The plants were clipped to ground level usually 10 weeks after planting and the yields of dry matter determined.

Soil tests were made according to Spurway's method (16), except as otherwise noted. In all cases the readings were checked against standard solutions.

TEST CROPS

The growth of different plant species on partially sterilized soil is discussed by Johnson (2). Some crops are very strongly inhibited in growth when grown on certain sterilized soils whereas others are not injured. In general, he found that *Gramineae* and *Cucurbitaceae* are resistant and that *Leguminosae* and *Solanaceae* are more susceptible to injury.

In the present trials red and Ladino clover showed very marked inhibition of growth; tomato, corn, and barley were intermediate; while ryegrass and buckwheat showed no injury.

It has long been known that heat treatments increase the readily available nitrogen in soils. For this reason sterilization of soils that are low in available nitrogen may result in increased growth of nonlegumes. In the present investigation, trials with certain nonlegumes showed that without nitrogen fertilizer, better growth was obtained in heated soil than in the control. Where nitrogen was added as needed to maintain optimum growth, the yields were higher in untreated soil than in heated soil. To avoid the problem of nitrogen fertilization, Ladino clover was used as the test crop in most of these trials.

EFFECT OF TEMPERATURE AND PERIOD OF INCUBATION AND STERILIZATION WITH AND WITHOUT PHOSPHATE FERTILIZATION

In earlier work (13), it was found that prolonged incubation of the soil at a maximum temperature of 45° C resulted in decreased plant growth, and that this deleterious effect could be corrected by a heavy phosphate application following incubation. The work of Lawrence and Newell (5) shows that phosphate applications also largely counteract the injurious effects of soil sterilization.

The effects of length of incubation period with several soils and different rates of phosphate fertilization are summarized in Table 1. In almost every case plant growth on soils fertilized with phosphate and then incubated at 3° C was as good as or better than growth on soils that were fertilized and planted immediately. In contrast, incubation at 40° to 45° C resulted in very poor subsequent plant growth, except where additional phosphate was applied following incubation (Fig. 1). Incubation for 17 weeks at 40° to 45° C was more injurious, as measured by inhibition of plant growth, than incubation for shorter periods, but the difference between the effects of incubation for 9 weeks and for 1 week was small (Fig. 2). Further trials with Hagerstown soil show that only a few hours at 45° C markedly reduced the growth of clover. With Dekalb subsoil, however, incubation appears to have increased the availability of some nutrient other than phosphate. Without incubation the yields were relatively poor on this soil regardless of the amount of phosphate applied.

The effects of various incubation temperatures and of steam sterilization on wet and dry Hagerstown soil was tested with Ladino

clover. As shown in Fig. 3, incubation for 1 week at 50° C or steam sterilization for 2 hours at 5 pounds pressure had similar effects on plant growth. With optimum soil moisture the critical temperature lies between 40° and 45° C for this soil (Table 2). With dry soil the critical temperature is somewhat higher.

TABLE 1.—*The effect of length and temperature of incubation of various soils on growth of Ladino clover as related to phosphate fertilization.*

Soils	pH value	Rate of phosphate fertilization, lbs. P_2O_5 per acre	Yield of dry matter, grams per pot*						
			Soil not incubated†	Soil incubated at 3° C for		Soil incubated at 40°–45° C for			
				9 weeks	17 weeks	1 week	5 weeks	9 weeks	17 weeks
Hagerstown silt loam	7.4	50	1.3	1.3	1.3	0.2	0.3	0.1	0.0
		150	2.1	2.8	2.1	0.5	0.6	0.2	0.0
		50+300‡	7.6	7.7	7.2	—**	—**	6.5	7.2
Hagerstown (subsoil)	7.2	150	0.7	0.8	—**	0.2	0.4	0.3	—**
		300	1.5	1.2	0.8	0.5	0.5	0.4	0.1
		150+400‡	6.2	7.0	6.3	—**	—**	7.1	7.5
Dekalb silt loam	6.1	50	1.7	1.5	—**	0.2	0.4	0.1	—**
		150	2.5	2.6	2.4	0.3	0.9	0.2	0.0
		300	4.2	3.7	3.6	0.9	1.2	0.7	0.1
		150+300‡	8.0	6.6	7.3	—**	—**	6.8	7.5
Dekalb (subsoil)	5.1	200	1.1	0.8	0.8	0.8	0.5	0.1	0.1
		400	1.8	1.6	2.2	1.9	1.4	0.6	0.5
		200+400‡	2.2	2.1	3.0	—**	—**	3.0	3.6
Dekalb silt loam	4.9	100	2.2	3.0	—**	—**	—**	0.2	—**
		100+300‡	6.1	7.4	—**	—**	—**	6.1	—**
Dekalb silt loam	5.6§	100	2.2	3.3	—**	—**	—**	0.2	—**
		100+300‡	6.1	7.4	—**	—**	—**	8.0	—**
Orangeburg fine sandy loam	5.8	None	0.4	1.0	—**	—**	—**	0.2	—**
		75	1.7	2.3	—**	—**	—**	0.6	—**
		150	3.9	4.1	—**	—**	—**	0.9	—**
		75+200‡	9.1	9.1	—**	—**	—**	8.8	—**

*Average of four pots.
†Fertilizer not applied until planting time.
‡This additional amount was applied in solution immediately after planting the crop.
§For this series the lime was mixed with the soil after the incubation treatment; prior to liming the pH value was 4.9.
**Not determined.

In all cases monocalcium phosphate at the rate of 300 pounds of P_2O_5 per acre added in solution as a topdressing following sterilization or incubation entirely overcame any injurious effects from heat treatments. It should be noted, however, that phosphate at the rate of 150 pounds of P_2O_5 per acre mixed with the soil following sterilization or incubation resulted in only slightly better growth than where the phosphate was applied before treatment.

Portions of Hagerstown soil were sterilized for different lengths of time and then seeded with Ladino clover. The yield data (Table 3) show that sterilization of this soil even for ½ hour was highly deleterious and that prolonged sterilization was even more injurious.

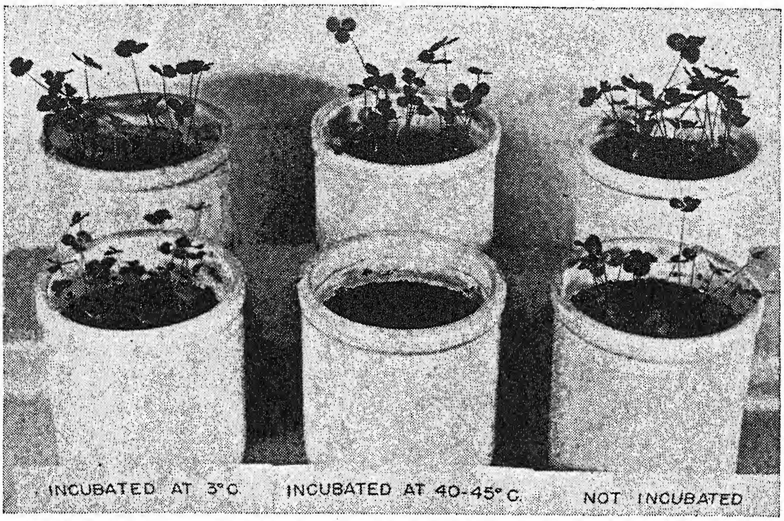


FIG. 1.—The effect of soil temperature and of phosphate fertilization on subsequent growth of Ladino clover on Dekalb soil. Front row received 300 pounds P_2O_5 per acre mixed with the soil. Back row received 150 pounds P_2O_5 mixed with the soil followed by 300 pounds additional in solution after the crop was planted. The length of the incubation period was 9 weeks.

These results are in agreement with those of Lawrence and Newell (5), who emphasized that sterilization for extended periods is harmful. Phosphate at the rate of 1,500 pounds of P_2O_5 per acre mixed with the soil prior to sterilization did not completely overcome the injurious effect, particularly when the soil was sterilized overnight. A topdressing of 300 pounds of P_2O_5 per acre added in solution following sterilization, however, was highly effective in overcoming the injury.

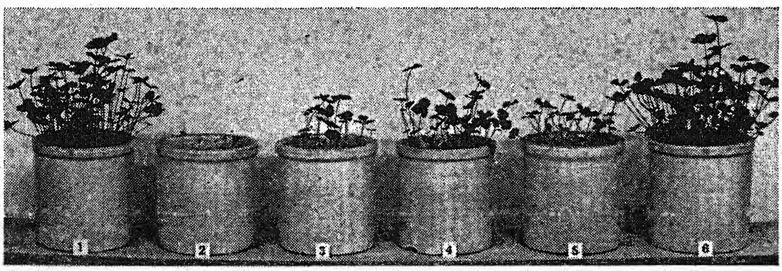


FIG. 2.—Effect of soil temperature and length of incubation period on growth of Ladino clover on Dekalb soil. All plots received 150 pounds P_2O_5 per acre mixed with the soil. The incubation treatments were as follows: 1, 17 weeks at 3° C; 2, 17 weeks at 40°–45° C; 3, 9 weeks at 40°–45° C; 4, 5 weeks at 40°–45° C; 5, 1 week at 40°–45° C; 6, not incubated.

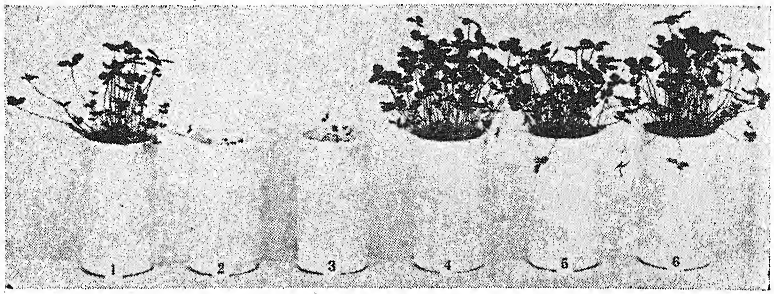


FIG. 3.—The effect of heat treatments and of phosphate fertilization of Hagerstown soil on the growth of Ladino clover. The treatments were as follows: 1, no treatment; 2, incubated 5 days at 50° C; 3, sterilized 2 hours at 5 pounds pressure; 4, P_2O_5 at 3,000 pounds per acre; 5, P_2O_5 at 3,000 pounds per acre; incubated 5 days at 50° C; 6, P_2O_5 at 3,000 pounds per acre; sterilized 2 hours at 5 pounds pressure.

RATE OF PHOSPHATE APPLICATION

The data presented in Tables 1 and 3 show that phosphate applied in solution as a topdressing following incubation or sterilization is much more effective than phosphate mixed with the soil prior to treatment. It may be questioned, however, whether this greater effectiveness is due largely to the time of application or to localization of the phosphate. To provide more data on this subject, samples of Hagerstown soil were fertilized at different rates and incubated 1 week at 50° C, while comparable samples were fertilized following incubation. In both cases the fertilizer was well mixed with the soil.

TABLE 2.—*The relation of soil temperature, soil moisture content, and phosphate fertilization to growth of Ladino clover on Hagerstown soil.*

Soil treatment	Yield of dry matter, grams per pot*: 150 pounds P_2O_5 per acre applied, Before soil treatment	Yield of dry matter, grams per pot*: 150 pounds P_2O_5 per acre applied, After soil treatment	Yield of dry matter, grams per pot*: Very high application of phosphate†
Control	0.47	0.47	0.7
Wet for 5 days at 40° C‡	0.51	—§	—§
Wet for 5 days at 45° C	0.08	—§	—§
Wet for 5 days at 50° C	0.03	0.12	1.0
Dry for 5 days at 50° C	0.31	0.43	0.8
Wet for 5 days at 70° C	0.02	0.13	—§
Dry for 5 days at 70° C	0.09	0.12	—§
Wet for 1 hour at 15 lbs. steam pressure	0.06	0.06	1.1
Dry for 1 hour at 15 lbs. steam pressure	0.09	0.11	1.0

*Average of three pots.
†150 pounds P_2O_5 per acre before treatment plus 300 pounds P_2O_5 added in solution immmediately after planting the crop.
‡Previous trials had shown no deleterious effect following incubation at temperatures between 3° and 40° C.
§Not determined.

TABLE 3.—*The effect of temperature treatments of Hagerstown soil on the growth of Ladino clover as related to phosphate fertilization.*

Soil treatment	Yield of Ladino clover, grams per pot*	
	200 pounds P_2O_5 per acre	1,500 pounds P_2O_5 per acre
Control	2.12	3.62
Incubated 6 days at 50° C	0.12	2.02
Sterilized 30 min. at 5 lbs. steam pressure	0.12	—‡
Sterilized 2 hrs. at 5 lbs. steam pressure	0.09	2.69
Sterilized 4 hrs. at 5 lbs. steam pressure	0.02	2.35
Sterilized overnight at 5 lbs. steam pressure	0.02	1.41
Sterilized overnight at 5 lbs. steam pressure	3.31†	1.41

*Average of three pots.
†Plus 300 pounds P_2O_5 applied in solution after planting the crop.
‡Not determined.

The test crops were Ladino clover and tomato. With tomatoes, ammonium nitrate was added as needed to maintain optimum growth. As a guide in determining nitrogen requirements, each treatment was started in quadruplicate, but two of the four replicates received an initial application of nitrogen whereas two did not. The plants were observed closely and more nitrogen added at the first indication of a deficiency. With the higher rates of phosphate, several nitrogen applications were necessary, but at the two lowest rates the growth was so poor on the incubated soil that no response to nitrogen was obtained.

TABLE 4.—*The relation of phosphate fertilization and temperature treatments of Hagerstown soil to plant growth.*

Phosphate treatments, lbs. P_2O_5 per acre	Not incubated	Incubated 1 week at 50° C, phosphate applied	
		Before incubation	After incubation
	Yield of Ladino Clover, Grams per Pot*		
None	0.3	—	—
150	1.0	0.1	0.2
300	1.1	0.2	0.2
600	1.3	0.4	0.6
1,200	1.3	1.5	1.4
2,400	1.5	1.7	1.6
4,800	1.2	1.7	1.5
	Yield of Tomato Plants, Grams per Pot†		
None	0.3	—	—
150	1.3	0.3	0.7
300	2.4	1.1	2.5
600	3.6	3.9	3.9
1,200	4.7	4.9	4.5
2,400	4.2	5.5	4.6
4,800	4.4	5.8	5.0

*Average of three pots.
†Average of four pots.

With both clover and tomatoes the incubation treatment caused a marked reduction in yield at the low phosphate levels (Table 4). Applying the phosphate after incubation rather than before increased the growth of the tomato plants but was of little help with the Ladino clover. At the high rates of phosphate, the incubated soils produced better growth than the controls. Trials with sterilized soil gave results similar to those obtained with incubated soil.

The data previously discussed in connection with Tables 2 and 3 show that incubating dry soil was less injurious than incubating wet soil and also suggest that prolonged sterilization, in addition to being more injurious than shorter periods of sterilization, may require more phosphate to overcome the resulting injurious effects. The data presented in Table 5, however, show that whether the soil was sterilized wet or dry was of minor importance as compared with the rate of phosphate applied.

TABLE 5.—*The relation of phosphate fertilization of unsterilized and sterilized Hagerstown soil to the growth of Ladino clover.*

Phosphate treatment, lbs. P_2O_5 per acre	Yield of Ladino clover, grams per pot*		
	Unsterilized soil	Soil sterilized 45 minutes at 5 lbs. steam pressure	
		Soil wet when sterilized	Soil dry when sterilized
150	0.7	0.02	0.02
300	0.8	0.06	0.06
600	1.2	0.7	1.0
1,200	1.0	1.6	1.6
2,400	1.2	1.3	1.6

*Average of two pots.

EFFECT OF SOIL INOCULATION

In general, the addition of small amounts of untreated soil following sterilization or incubation had very little immediate effect on plant growth but did very materially shorten the duration of the inhibiting effect.

Adding different amounts of untreated soil following sterilization and incubation was tried on Hagerstown soil. Since the unfertilized soil would not support good growth of clover, phosphate at the rate of 200 pounds P_2O_5 per acre was mixed with the soil. Subsamples of this lot of fertilized soil were sterilized for 2 hours at 5 pounds steam pressure; others were incubated 5 days at 50° C; and others were left as controls. Following the heat treatments, the soils were mixed with varying amounts of the original unfertilized soil (Table 6). Ladino clover was then seeded and plant growth determined. For the first 7 or 8 weeks following sterilization or incubation, the growth was proportional to the amount of untreated soil added. Mixtures consisting of 75% untreated soil produced better growth than mixtures containing either 5% or 30%, despite the fact that the rate of added phos-

phate was much lower. At the end of 12 weeks, however, the yields (Table 6) were about the same for the mixtures containing 5, 30, and 75% untreated soil. It is of interest to note, however, that only the mixtures containing 75% untreated soil produced as good growth as the corresponding control.

TABLE 6.—*Plant growth on heat-treated soil as affected by adding varying amounts of untreated soil.*

Percentage of untreated soil in the mixture	Pounds P_2O_5 added per acre†	Yields of Ladino clover, grams per pot*		
		Control	Sterilized soil‡	Incubated soil§
None	200	2.1	0.1	0.1
None (soil repotted)	200	—	0.1	0.1
5	190	—	1.0	1.0
30	140	1.6	1.0	1.1
75	50	1.0	0.9	1.0

*Average of three pots.
†The heated soil as well as the control was fertilized at the rate of 200 pounds P_2O_5 per acre, whereas the untreated soil mixed with it received no phosphate. This accounts for the differences in rate of fertilization.
‡Two hours at 5 pounds pressure.
§Five days at 50° C.

EFFECT OF METHOD OF PLANT ESTABLISHMENT

In trials with Ladino clover it was noted that when young seedlings were transplanted to partially sterilized soil an occasional plant would make normal growth while other plants in the same pot would make practically no growth. In view of these results the effect of partial sterilization was determined in relation to the size of the transplanted seedlings of clover. The results of this trial are summarized in Table 7.

TABLE 7.—*The effect of method of plant establishment on the growth of Ladino clover on partially sterilized soil.*

Method of plant establishment	Yield of dry matter, grams per pot*		
	Control	Sterilized soil†	Incubated soil‡
Seeding	2.1	0.1	0.1
Transplanting seedlings§	3.3	1.2	0.8
Transplanting large plants**	3.4	2.5	2.1

*Average of three pots.
†Two hours at 5 pounds steam pressure.
‡Six days at 50° C.
§Plants with three trifoliate leaves.
**The total dry weight of these plants at the time of transplanting averaged 0.3 gram per pot.

When the clover was started from seed, the yield on sterilized soil was only 0.1 gram per pot as compared with 2.1 grams for the control. With seedlings as the test crop, the sterilized soil produced 1.2 grams of dry matter as compared with 3.3 grams for the control. When larger plants were used the yields were 2.5 and 3.4 grams, respectively,

for the sterilized soil and control. The results with incubated soil, also shown in Table 6, were similar to those with sterilized soil. These data support earlier observations that if the plants once become sufficiently well established they will grow well on sterilized or incubated soil.

POSSIBLE SOIL FACTORS AFFECTING GROWTH OF CLOVER

PHOSPHORUS

Although applications of phosphate correct the injurious effects of soil sterilization and incubation, there is evidence that the trouble is not due to phosphate fixation, as was suggested in an earlier publication (13).

In the first place it seems unlikely that soil sterilization would markedly inhibit the growth of certain crops, whereas other crops that also show a marked response to phosphate fertilization would not be inhibited.

Another indication of the phosphate available to the plant is the total amount removed in the crop. A number of early investigators found that heating a soil not only increased subsequent growth of certain plant species but increased the percentage content of phosphorus, nitrogen, and potassium. Some of this early work is reviewed by Johnson (2).

In most of the present investigations plant growth was so poor on heated soil as compared with the controls that phosphorus analyses of plant material would be of little value in determining phosphate availability. The results obtained by transplanting large plants of Ladino clover, however, indicate that incubation at 50° C did not decrease phosphate availability (Table 8).

TABLE 8.—*Phosphate availability on Hagerstown soil incubated for 1 week at 50° C as measured by transplanted Ladino clover.**

Soil treatment	Yield of clover, grams per pot	Total phosphorus in plants, mg per pot
None	1.33	3.06
Incubated	1.43	3.63

*Treatments were in quadruplicate. Analysis of variance showed no significant differences in total yields or in phosphorus uptake by the plants.

Chemical determinations of available phosphorus by Truog's method (18) and by Merkle's method (7) modified to permit the use of a KWSZ photometer showed no decrease in soluble phosphorus following sterilization or incubation. Moreover, as already shown, the amount of phosphate required to overcome the injurious effect of sterilization or incubation was almost as great when the phosphate was applied after the heat treatment as when applied before. This is further evidence that phosphate fixation is not the cause of the trouble.

Additional evidence on this subject was obtained in a trial involving the use of clay pots and paraffin-coated tin cans. As shown in Table 9, high rates of phosphate fertilization resulted in high yields

of clover irrespective of soil treatment or soil container. With the lowest rate of phosphate the unsterilized soil produced only one-third as much plant growth in clay pots as in tin cans. With sterilized soil, however, the growth, although poor, was much better in clay pots than in tin cans. Chemical studies showed that the soil in the clay pots had been leached almost free of soluble salts. This was attributed to rapid evaporation from the sides of the pots. Thus, it appears that continuous leaching of unsterilized soil decreased growth due largely to a removal of available phosphorus. That phosphate was the principal limiting factor in the untreated soil is shown by the high yields obtained where additional phosphate was added. In sterilized soil presumably the available phosphate was also decreased by leaching, yet plant growth was improved.

TABLE 9.—*A comparison of clay pots vs. paraffin-coated tin cans in evaluating the injurious effect of soil sterilization.*

Soil treatment	Yields of Ladino clover, grams per pot*				
	200 pounds P_2O_5 per acre		1,500 pounds P_2O_5 per acre		5,000 pounds P_2O_5 per acre in clay pots
	Tin cans†	Clay pots	Tin cans†	Clay pots	
Control	2.1	0.7	3.6	2.7	2.8
Sterilized 2 hrs. at 5 lbs. pressure	0.1	0.4	2.7	2.7	3.3

*Average of three pots.
†Other trials have shown that growth in tin cans is similar to that in glazed pots.

AMMONIA, NITRATES, TOTAL SALTS, AND MINOR ELEMENTS

The results previously discussed suggest that a toxic concentration of some substance may have been produced as a result of soil sterilization and that leaching decreased the concentration. This idea was advanced as early as 1910 by Pickering (11), who concluded that, although heating the soil increases plant food and thus tends to increase growth, it also produces toxic substances which tend to arrest growth, particularly heating at temperatures above 100° C.

Newhall (10) reported increases of two to ten times in soluble salts following soil sterilization and in some cases severe injury resulted. Laurie (4) stated that nitrates and total soluble salts reach a peak 4 to 6 weeks after sterilization and that where nitrates are high in the original soil injury may result at this time.

A similar line of reasoning would also apply in the case of certain other elements particularly since Milliken (8) reported increases in the amounts of zinc, manganese, copper, calcium, phosphorous, potassium, and nitrogen available to plants following sterilization. Piper (12) found increases in copper and manganese, and Naftel (9) reported an increase in water-soluble boron.

McCool (6) found that plants grown in steamed soils contained large amounts of manganese and developed leaf symptoms similar,

if not identical, to those produced in soils to which excessive amounts of manganese were applied. He also reported that commercial fertilizer corrected the injurious effect of sterilization.

Hoffman (1) attributed the injury following sterilization of certain soils to an accumulation of ammonium carbonate and reported that liberal applications of calcium sulfate prevented the injury.

Lawrence and Newell (5) attributed the injury to an unbalanced phosphate-nitrogen relationship which could be corrected by applications of phosphate.

Manganese.—On the Hagerstown soil, as already shown, plant growth was about equally poor on steam-sterilized soil and on soil incubated 1 week at a temperature of about 50° C. Yet the sterilized soil tested about 60 pounds per acre of soluble manganese by the Spurway method (16), whereas both the incubated soil and the control showed only a trace. Moreover applications of phosphate corrected the injurious effect of sterilization without appreciably affecting the soluble manganese content, whereas lime decreased the soluble manganese without improving plant growth. These results indicate that the trouble cannot be attributed to an excess of soluble manganese.

Another approach to this problem involved the addition of manganese sulfate to unsterilized soil at rates of 200, 500, 1,000, 2,000, 4,000, and 8,000 pounds per acre. Normal growth of clover was obtained, except at the 8,000 pound rate. This latter treatment not only decreased the rate of growth but resulted in necrotic plants. Sterilization, on the other hand, inhibited growth but did not cause necrosis. Lime corrected the injurious effect of excessive amounts of manganese sulfate whereas phosphate did not. This is just opposite to their effects on sterilized soil. In order to be certain that manganese rather than sulfate was the toxic ingredient of manganese sulfate in these trials, calcium sulfate was added to other samples of the same soil to supply the same amount of sulfate as was added in the form of manganese sulfate. Calcium sulfate did not inhibit plant growth.

Although these results indicate that the injurious effect of soil sterilization cannot be attributed to a toxic concentration of manganese, it should not be concluded that toxic concentrations of manganese will not occur on other soils. In fact, preliminary trials on strongly acid soils substantiate the findings of McCool (6) that necrotic symptoms similar to those due to manganese toxicity were obtained following sterilization.

Nitrates and soluble salts.—Although excess soluble salts and high nitrate concentrations may be important factors on some soils, it appears that in the present trials the trouble cannot be attributed to either of these factors. Samples of Hagerstown soil were taken from the same area at different times of the year, thereby obtaining soils of widely different soluble salt content. In another case the soil was leached before being used in the trials. In all cases incubation or sterilization resulted in very poor plant growth.

Periodic soil tests showed that incubation and sterilization increased the soluble salt content, as measured by the resistance of a 1 to 2½ soil-water suspension, an average of about 10% and usually

resulted in a slight decrease in nitrate nitrogen followed later by a slight increase. These soil differences, however, were not as great as those due to leaching or to sampling at different times during the year. To cite extreme cases excellent growth was obtained on controls testing 200 pounds per acre of nitrate nitrogen and 2,200 ohms specific resistance on a 1 to 2½ soil-water suspension, whereas sterilized and incubated soils produced very poor growth with nitrate nitrogen concentrations as low as 30 pounds per acre and specific resistances of 7,200 ohms.

In another trial on the same soil ammonium nitrate was added to unsterilized soil at rates of 100, 200, 400, 800, and 1,600 pounds per acre and the growth of clover compared with that on soils sterilized and incubated but without added nitrogen. Except at the highest rate, ammonium nitrate did not produce injurious effects, whereas sterilized and incubated soil gave very poor growth. Periodic determinations of nitrate nitrogen and of total soluble salts showed that with 800 pounds of ammonium nitrate the nitrate nitrogen content increased from 150 pounds per acre at the beginning of the trial to 275 pounds 6 to 8 weeks later. The sterilized and the incubated soils as well as the controls gave readings ranging from 20 to 40 pounds per acre. The total salt concentration, based on the resistance of 1 to 2½ soil-water suspensions showed similar differences. With 800 pounds of ammonium nitrate the specific resistance decreased from an initial reading of 2,900 ohms to 1,900 ohms 6 weeks later. The sterilized and incubated soils gave readings ranging from 6,700 to 9,800 ohms, while the control tested about 8,400 ohms.

Ammonia.—Tests of a similar nature to determine the tolerance of clover for ammoniacal nitrogen is complicated by the fact that ammonia added to unsterilized soils is soon nitrified. In the Hagerstown soil used in these studies the concentration of ammonium nitrogen in either incubated or sterilized soil did not exceed 40 pounds per acre. After about 4 weeks the ammonium concentration gradually decreased and at the end of 6 weeks averaged 15 pounds per acre. These amounts would not be expected to cause trouble in view of the conclusion of Spurway (17) that a concentration above about 330 pounds per acre of ammonium nitrogen (50 p.p.m. of ammonia in the extracting solution) is toxic to plants.

Heavy applications of phosphate have not decreased the ammonia content of either incubated or sterilized soil as determined by Spurway's method, yet have resulted in excellent plant growth. This is further evidence that the ammonia concentration is not excessively high.

If ammonia accumulation were the principal source of trouble, it would also be expected that after the ammonia concentration decreased, plants would grow normally. Repeated trials have shown that this is not the case.

Calcium sulfate.—Hoffman (1) overcame the injurious effect of soil sterilization by adding large amounts of calcium sulfate. In the present trials on Hagerstown soil, however, calcium sulfate at rates of 1,000 and 2,000 pounds per acre was ineffective.

Other elements.—Soil tests by Spurway's method (16) showed no evidence of accumulation of iron, aluminum, chlorides, nitrites, or sulfates following sterilization or incubation of Hagerstown soil. No determinations were made of organic compounds in the soil.

SUMMARY AND CONCLUSIONS

The deleterious effect of steam sterilization of certain soils on plant growth was entirely overcome by heavy applications of phosphate either before or after sterilization. The injurious effect of sterilization, however, apparently was not due to phosphate deficiency caused by fixation.

The trouble appears to be due to a toxic concentration of some substance. Although this substance has not been identified, the evidence indicates that it is not nitrate, nitrite, ammonia, manganese, aluminum, iron, chloride, sulfate, or total soluble salts. It seems unlikely, however, that the same factor or factors are necessarily responsible for injury on all soils.

Incubation for a few days at 50° C had about the same effect on plant growth as steam sterilization for 2 hours at 5 pounds pressure. The duration of the incubation period was of minor consideration as compared with the temperature of incubation. The critical temperature appeared to be somewhere between 40° and 45° C for a soil incubated wet. For a dry soil it was somewhat higher.

In steam-sterilized soil, plant growth was about the same whether the soil was wet or dry during sterilization.

Inoculation of heat-treated soil with untreated soil had little immediate effect on plant growth but very materially shortened the duration of the inhibiting effect.

Of the crops tested, Ladino and red clover were particularly sensitive to injury; tomato, barley, and corn were intermediate; and ryegrass and buckwheat were not injured.

LITERATURE CITED

1. HOFFMAN, I. C. Injuries following greenhouse soil sterilization, causes and control. Ohio Veg. Growers' Assoc., 24:60–64. 1939.
2. JOHNSON, JAMES. The influence of heated soils on seed germination and plant growth. Soil Sci., 7:1–103. 1919.
3. ————. Steam sterilization of soil for tobacco and other crops. U.S.D.A. Farmers' Bul. 1629. 1930.
4. LAURIE, ALEX. Effect of steam sterilization on the soluble salts of soils. Ohio Veg. Growers' Assoc., 25:111–123. 1940.
5. LAWRENCE, W. J. C., and NEWELL, J. Seed and potting composts. London: Allen and Unwin. 1939.
6. MCCOOL, M. M. Effect of various factors on the soluble manganese in soils. Contr. Boyce Thompson Inst., 6:147–164. 1934.
7. MERKLE, F. G. Soil testing–operation, interpretation and application. Pa. Agr. Exp. Sta. Bul. 398. 1940.
8. MILLIKAN, C. R. Studies on soil conditions in relation to root-rot of cereals. Proc. Roy. Soc. Victoria, 54 (N.S.):145–195. 1942.
9. NAFTEL, JAMES A. Recent studies on boron in soils. Amer. Fert., 89(7):5–8, 24, 26. 1938.
10. NEWHALL, A. G. Control of root-knot nematode in greenhouses. Ohio Agr. Exp. Sta. Bul. 451. 1930.
11. PICKERING, S. U. Plant growth in heated soils. Jour. Agr. Sci., 3:277–84. 1910.

12. Piper, C. S. Investigations on copper deficiency in plants. Jour. Agr. Sci., 32:143–178. 1942.
13. Robinson, R. R. Phosphorus fixation as affected by soil temperature. Jour. Amer. Soc. Agron., 34:301–306. 1942.
14. Russell, E. J., and Petherbridge, F. R. On the growth of plants in partially sterilized soils. Jour. Agr. Sci., 5:248–287. 1913.
15. Schreiner, Oswald, and Lathrop, E. C. The chemistry of steam heated soils. Jour. Amer. Chem. Soc., 34:1242–59. 1912.
16. Spurway, C. H. Soil testing, a practical system of soil fertility diagnosis. Mich. Agr. Exp. Sta. Tech. Bul. 132 (2nd revision). 1938.
17. ————. Soil fertility control for greenhouses. Mich. Agr. Exp. Sta. Spec. Bul. 325. 1943.
18. Truog, Emil. The determination of the readily available phosphorus of soils. Jour. Amer. Soc. Agron., 22:874–882. 1930.

A YEAR-AROUND GRAZING PROGRAM FOR THE ALKALINE SOILS OF THE BLACK BELT OF ALABAMA[1]

K. G. Baker and E. L. Mayton[2]

THE Black Belt of Alabama, an irregular strip of land extending across the central part of the state, is approximately 170 miles long, east by west, and 20 miles wide, north by south. It is estimated that this area comprises about 2,331,000 acres. The approximate elevation of the Black Belt is 200 feet above sea level and the rainfall is approximately 50 inches, varying within the last 61 years from 36 to 76 inches. All of the soil types within the Black Belt proper are stiff heavy clays, ranging in reaction from strongly basic (pH 8.0) to very acid (pH 4.1).

Previous to the advent of the boll weevil in 1914, the Black Belt area was devoted almost exclusively to the production of cotton as a money crop, with small acreages in corn to supply the partial grain needs for work stock and food for the labor. The heavy winter rainfall on these stiff clay soils prevented early planting of cotton and rushing the crop to maturity ahead of the boll weevil as was possible on lighter soils; thus, this territory suffered more from the advent of the cotton insect pest than did any other section. As a result many acres that had previously been devoted to cotton were abandoned and were allowed to grow up in brush, sedge, and wire grass.

While the Black Belt was still a cotton-producing area, Johnson grass had been introduced as a hay plant. This plant was so well adapted to the well-drained lime soils that it took over as land was abandoned for cotton production. The farmer found that he could cut and bale this crop, and sell it to other areas as a money crop. Johnson grass then became a very important source of income to many cotton farmers. However, as industries replaced horses and mules with other kinds of power, and as farmers increased their own production of hay under the cotton acreage reduction program, the hay producer's outlets became very limited. Therefore, it was necessary to find other uses for this land.

To assist in developing a program for the utilization of the land, the Black Belt Substation was established near Marion Junction, Ala., in 1930. Considering the natural tendency of this area to grow grass and clover, the logical research program was to discover the means of stimulating growth of these plants, and to build a livestock management system that would convert them into marketable products.

---

[1]Contribution from the Department of Agronomy and Soils, Alabama Polytechnic Institute, Auburn, Ala. Presented by the senior author at the annual meeting of the American Society of Agronomy, Cincinnati, Ohio, November 12, 1943. Received for publication April 4, 1944.

[2]Superintendent of the Black Belt Substation, Marion Junction, Ala., and Associate Agronomist, Alabama Agricultural Experiment Station, Alabama Polytechnic Institute, Auburn, Ala., respectively.

PASTURE PROJECT

In 1931 a plan was made for research on pastures on the lime soils. The original plan included fertilizer treatments for 15 4-acre plots, each plot containing 1 acre of upland and 3 acres of bottom land. In 1936 the plot arrangement was revised so that only the 3 acres of bottom land were included in each plot.

OBJECTIVES

The purposes of this program of research were as follows: (1) To find the best-adapted group of plants for pasture purposes; (2) to determine the economic value of each of the common fertilizer elements, namely, nitrogen, phosphorus, and potash applied at certain rates; (3) to determine the seasonal distribution of gains and the carrying capacity of plots fertilized with varying amounts of phosphates; (4) to compare large amounts of phosphate applied at 3-year intervals with smaller applications made annually; (5) to determine the effect of fertilizers on the chemical composition of plants; (6) to determine the value of barnyard manure when applied to a pasture; and (7) to develop supplementary pastures that, together with a permanent pasture, would furnish year-around grazing.

PROCEDURE APPLYING TO ALL PLOTS

All plots involved in this discussion were given the following similar treatments:

All received the same amounts and kinds of seed.

The land was turned and disked in 1931, no later cultivation has been done on any of the plots. Since that time all fertilizers have been applied as a top-dressing in the fall, except nitrogen which has been applied annually in the spring and summer.

The results were measured on all plots both by recording gains made by beef cattle and by the weight and analysis of clippings from protected areas.

Grazing all plots as evenly as possible was attempted by varying the number of animals according to the condition of the pasture.

In the main, 2-year-old steers that had been on maintenance ration throughout the winter period were used in this experiment.

As animals became finished, others were substituted.

All animals were weighed at 28-day intervals.

Because the pasture plants were in the process of becoming established in 1932, the grazing records during that season are not considered in this discussion.

RESULTS

PASTURE PLANTS

In the fall of 1931, all plots received a mixture of seed sufficient for a stand of the following: White clover, black medic, and biennial white and annual yellow sweet clovers. Seed sufficient to produce a stand of Dallis grass, red top, and orchard grass were sown on all plots the following spring. In 1935 Kentucky bluegrass was sown at the rate of 5 pounds per acre. No additional seeding of any kind has been done. However, heavy grazing, weather extremes, and competition with other plants have taken a toll. Several of these species have been eliminated in the 12 years. The predominant species now are black medic, white clover, Dallis grass, and bluegrass. Bluegrass did very well on the lime soils where phosphate was applied. However, bluegrass is not as desirable for pasture as is a rotation of the adapted clovers and Dallis grass. Because of its tendency to crowd out the other grasses and especially the clovers, bluegrass subsequently suffers from the lack of nitrogen. The natural rotation of clovers and grasses works almost ideally. The clovers predominate in the early

season, and then give way to Dallis grass in the latter part of the season. The clovers leave sufficient nitrogen in the ground to stimulate greatly the later grass crop.

NITROGEN

While no plots in this series received an application of nitrogen alone, there are plots that receive nitrogen as a top-dressing in the spring following the annual fall applications of mineral fertilizers. In no instance did the application of nitrogen show a sufficient increase in beef yields to justify its use on Black Belt pastures (Table 1). It has been observed that where nitrogen is used it seems to depress both the stands and the growth of clovers. If the needs for mineral fertilizers are supplied, the stimulated clovers provide the nitrogen needed for a grass crop, and it is apparent that it is a better practice to meet the nitrogen requirements through the stimulation of a legume crop than by the purchase and application of commercial nitrogen.

VALUE OF PHOSPHATES

In all experiments at the Black Belt Substation on all soil types and with all crops, including both pasture and field crops, there has been, without exception, a remarkable response to the application of phosphate. Chemical analysis of the soils in this area shows an abundance of phosphate. However, this phosphate is "tied up" in a compound that cannot be used by the plants. Likewise, a great percentage of the phosphate added also becomes "tied up". In the series of plots considered in this discussion, there are plots receiving annual applications of 200, 400, and 800 pounds of 16% superphosphate, respectively. Also, there are corresponding plots receiving once in 3 years applications of 600, 1,200, and 2,400 pounds of superphosphate, respectively. There are additional plots where potash and nitrogen are added. The results indicate that higher yields may be expected from periodic heavy applications than from annual lighter applications, although either method of using phosphate is profitable. There is a definite indication that the best rate at which to apply super-

TABLE 1.—*Returns per acre from the use of fertilizers on Black Belt pastures, 10-year period, 1933–42.*

Treatment, lbs. per acre	Frequency of application	Average annual yield of beef, lbs.	Increase from fertilizer, lbs.	Annual fertilizer cost*	Value above fertilizer cost†
Superphosphate, 1,200	3 years	352	166	$3.20	$21.44
Superphosphate, 600	3 years	276	90	1.60	17.72
None	—	188	—	—	13.02
Superphosphate, 200	Annual	241	55	1.60	13.67
Superphosphate, 400	Annual	307	121	3.20	18.29
Superphosphate, 800	Annual	306	125	6.40	15.02
Superphosphate, 800; nitrate of soda, 250	Annual	354	174	10.65	14.13

*Superphosphate 80 cents per 100 pounds and nitrate of soda $1.75 per 100 pounds.
†Beef valued at 7 cents per pound.

phosphate is approximately 1,200 pounds per acre once in 3 years, or 400 pounds annually.

The fertilizer treatments and the performance of seven plots over a period of 10 years are given in Table 1. The value per acre above fertilizer cost is the highest on the plot receiving 1,200 pounds of superphosphate every 3 years. However, it is significant that all rates of phosphate application paid a profit in beef yields, irrespective of whether the applications were annual or every 3 years.

In Fig. 1 is presented the seasonal distribution of gains made by beef cattle on three plots over a 10-year period. The high-yielding plot received 1,200 pounds of 16% superphosphate at 3-year intervals; the second high-yielding plot received 600 pounds at 3-year intervals; and the lowest yielding plot received no fertilizer. During the early spring the gain per acre per day made by cattle grazing these plots was approximately in direct proportion to the amount of the phosphate applied.

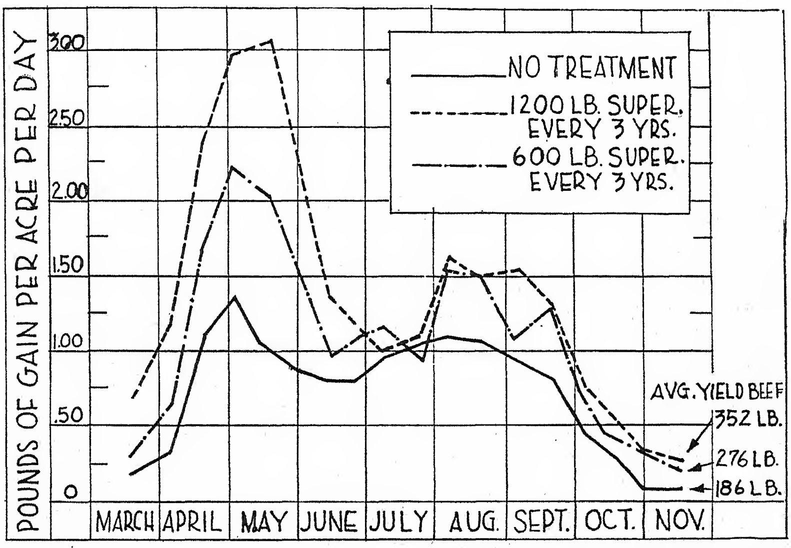


FIG. 1.—Seasonal distribution of gain from pasture, 10-year average, 1933–42.

EFFECT OF POTASH

The performance of two plots showing the total annual gain per acre is given in Fig. 2. During the first seven years of the experiment, 1932 to 1938, the plot receiving 800 pounds of superphosphate yielded an average of 50 pounds of beef more per acre per year than did the 400-pound plot. During the last 4 years of the test, 1939 to 1942, the 400-pound plot outyielded the heavier fertilized plot by 83 pounds of beef per acre per year. After 7 years white clover on the plot receiving 800 pounds of superphosphate began to show characteristic symptoms of potash deficiency. This fact led to the conclusion that continuous heavy applications of phosphate on Black Belt soils developed a potash deficiency.

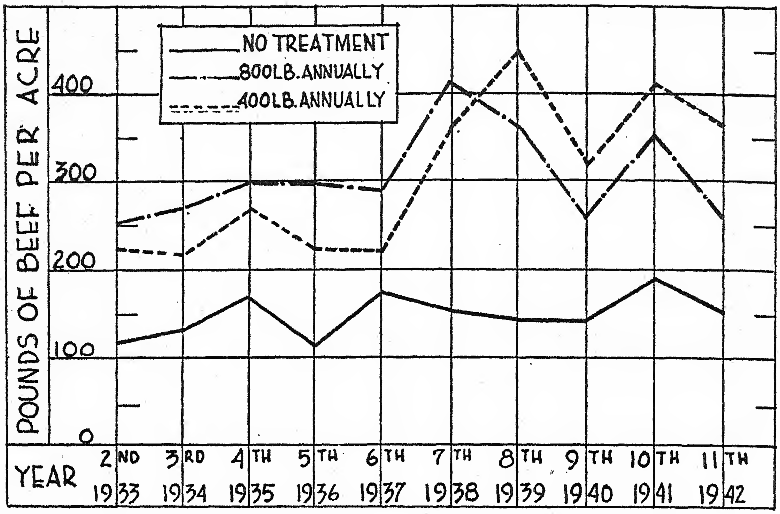


FIG. 2.—Yield of beef per acre from 400 and 800 pounds of superphosphate annually. After the seventh year potash became a seriously limiting factor at the high phosphate level.

The effect of potash is further shown by the yields of two other plots over the 10-year period as presented in Table 2. It will be noted that the average annual increase from potash during the first 4 years of the experiment was 15 pounds of beef per acre, whereas the increase during the last 6 years was 80 pounds per acre.

TABLE 2.—*Returns per acre from potash as an addition to phosphate and nitrogen on Black Belt pastures, 10-year period, 1933–42.*

Treatment, lbs. per acre	Frequency of application	Average annual yield of beef, 1933–36, lbs.	Increase due to potash, 1933–36, lbs.	Average annual yield of beef, 1937–42, lbs.	Increase due to potash, 1937–42, lbs.
Superphosphate, 800; nitrate of soda, 250......	Annually	298	—	391	—
Superphosphate, 800; nitrate of soda, 250; muriate of potash, 100......	Annually	313	15	471	80

EFFECT OF BARNYARD MANURE

The value of barnyard manure as a fertilizer is shown in Fig. 3. This record is divided into two periods. The first period represents the gains of beef per acre on two plots for the first 9 years, beginning in 1932 and extending through 1940. The higher yielding plot received 5 tons of manure per acre at 3-year intervals, or a total of 15 tons during the 9-year period. The lower yielding plot received no fertilizer of any kind. A total of 15 tons of barnyard manure applied

at the rate of 5 tons per acre at 3-year intervals over a period of 9 years produced an average annual increase per acre of 32 pounds of beef. If the value of the beef is calculated at 7 cents per pound, barnyard manure used alone as a pasture fertilizer would have a value of $1.33 per ton.

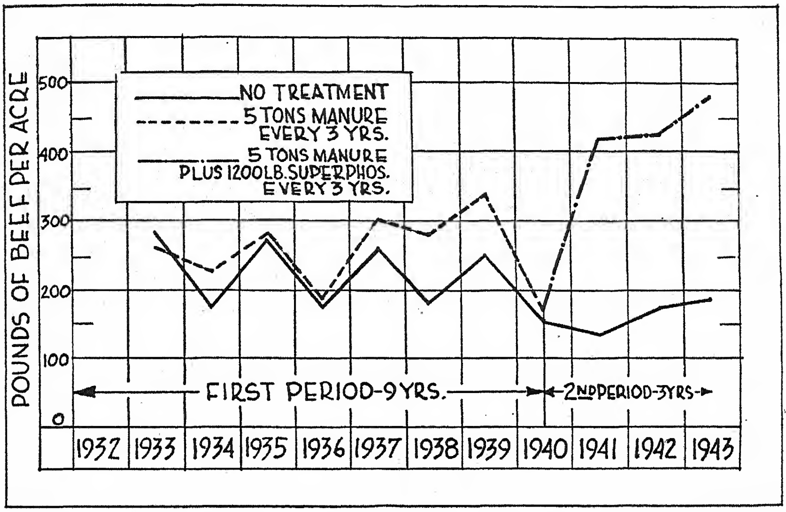


FIG. 3.—Yield of beef from manure supplemented with superphosphate.

During the second period of 3 years, the manure plot continued to receive 5 tons of barnyard manure at 3-year intervals and, in addition, received an application of 1,200 pounds of 16% superphosphate at the same intervals. As in the first period, the other plot received no treatment. During this period the combination of manure and phosphate produced an annual average of 249 pounds of beef per acre more than the no-treatment plot, emphasizing again the necessity of phosphate for the Black Belt pastures.

In the system of livestock production, particularly with reference to beef cattle as is suggested in this discussion, the cattle are grazed on pastures the year around; therefore, no manure is accumulated under shelter. Since the cattle are grazed on lands where the feed is produced and the manure is dropped directly on the same soil, anything affecting the value of manure becomes important. It has been observed that in fields where cattle were wintered the stimulation to plant growth was much greater from droppings on areas that had received an application of phosphate than from droppings on other fields that had not received any phosphate.

SEASONAL DISTRIBUTION OF GRAZING FROM PERMANENT PASTURES

Fig. 4 is the graph record of the plot that received 1,200 pounds of 16% superphosphate once every 3 years since 1931. The grazing season began about March 19 and extended until about November 1.

Beginning in March there was a consistent rise in the gains per acre and in the number of cow-days, both of which reached a peak for the entire season about May 9. There was a decline in both beef production and carrying capacity from about May 9 until the latter part of July. Another increase occurred for about 30 days after the July rains, which was followed by a sharp decline. The protein produced per acre follows somewhat the same general pattern.

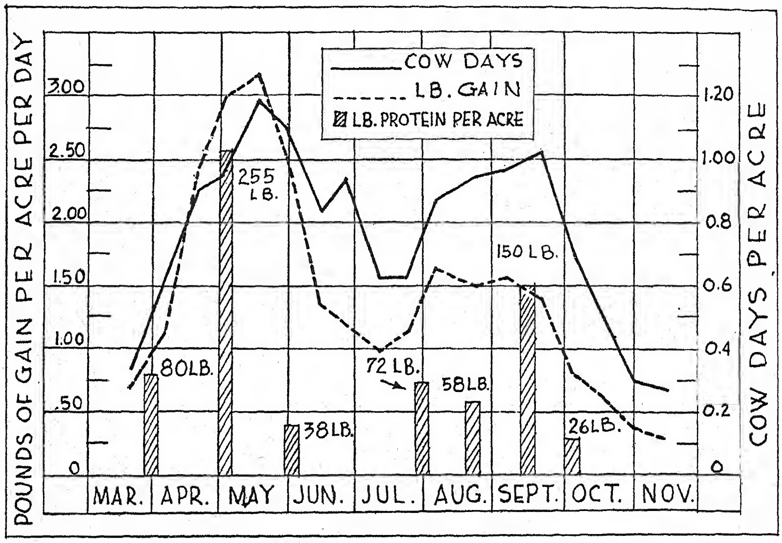


FIG. 4.—Comparison of seasonal distribution of gain and carrying capacity on Black Belt pastures receiving 1,200 pounds of superphosphate every 3 years, 10-year period, 1933–42.

There are two general causes for a recession in gains and carrying capacity. The decline as indicated from May until July comes every year, because black medic and white clover mature seed and die during this period. The exact dates for this low point depend to a very great extent upon prevailing weather conditions. However, a period of short grazing may be expected some time between May and July regardless of weather. This condition exists even on unfertilized plots, as shown in Fig. 1.

The lapse in grazing and carrying capacity is greatly emphasized by the use of phosphates. The phosphate stimulates the clover growth to such an extent that the grasses are held in subjection. When the clover crop dies, some time has to elapse and moisture content of the soils usually has to be increased before the grasses take over and furnish abundant grazing.

The second inevitable decline in the carrying capacity of the pasture and in ability to produce gains begins in the fall and extends through the winter period.

Occasional drought may occur during the grazing season, and will cause an additional lapse in grazing value of pasture. This, however, is not reflected in the graph.

It will be observed that the beef production capacity goes steadily up from the beginning of the season from a small gain per acre per day to the high daily gain of 3.11 pounds in May. This is followed by a decline to the low point in July of 1 pound per day. The number of cow-days, or carrying capacity, begins in March and reaches a peak of 1.10 animal units per acre per day at about the same date in May as the weight gains. The decline is rather rapid, reaching the low point of 0.64 animal units per acre per day in July. This means that the same acre of land that will support one steer per acre in May and produce a gain of 3.11 pounds, rapidly declines until the same acre in July supports 0.64 steer and puts on a daily gain of 1 pound.

PASTURE MANAGEMENT

Pasture management on lime lands in the Black Belt of Alabama, if it is granted that phosphate and potash should be used, resolves itself into devising a plan to take care of the low-yielding periods, two of which occur annually and the third a drought, that may occur at any time.

The best plan of supplementing a permanent pasture to the extent that a maximum of grazing may be realized the year around is to provide areas that will grow a rotation of Johnson grass and the early clovers. If Sumter soil, the eroded, well-drained upland, is to be used for this area and 200 to 400 pounds of superphosphate is applied, a rotation of black medic with Johnson grass will provide the necessary reserve for the weak grazing periods previously pointed out. The number of acres in this area should be approximately the same as the acreage in permanent pasture. The general plan is to utilize the permanent pasture to the extent consistent with good livestock and pasture management and to hold the supplementary area in reserve for use when necessary. Under favorable weather conditions it is not necessary in some years to use any of this supplementary area for grazing until fall. In this event the first growth of Johnson grass may be mowed and stacked for additional winter feed. It has been found that the second growth may be left standing in the field and will furnish the roughage requirements for animals as long as it lasts. It is a good practice to feed animals a small amount of protein concentrate when they are grazed through the winter on frosted matured Johnson grass.

SMALL GRAINS AS SUPPLEMENTARY GRAZING

On certain soil types in the Black Belt oats and barley may be grown in rotation with Johnson grass. It is possible to produce these crops and have a good yield of Johnson grass to follow without any additional seeding, cultivation, or fertilizer costs for the grass crop, provided the small grain crop is well fertilized. Oats are somewhat better adapted for winter grazing than barley, because they may be planted safely at an earlier date in the fall, thereby getting a better start for winter pasturing. Oats for winter grazing and for the production of grain are planted in September, whereas in some years barley may be destroyed by root rot if planted this early.

On dairy farms in the Black Belt, the expensive practice of breaking the tough soils for small grain production may be justified because of the greater need for grain and of the relative importance of providing a succulent winter grazing crop. In the case of beef cattle, consideration should be given the alternative of supplying winter grazing by using a rotation of Johnson grass and legumes that do not require annual breaking or seeding. However, the plants adapted to the soil types of each individual farm should be the determining factor in the formulation of a grazing program.

SUMMARY

This paper presents work done on the lime soils of the Black Belt of Alabama and the results are specifically applicable only under the conditions prevailing there. However, many of the basic problems encountered here are more or less common to all grazing areas. The results may be summarized as follows:

1. Black medic, white clover and Dallis grass are the best plants for permanent pasture on the alkaline soils of the Black Belt.
2. Applications of 200 to 400 pounds of superphosphate, and 50 to 100 pounds of muriate of potash per acre annually, or correspondingly heavier applications at 3-year intervals should be used on both permanent and temporary pastures.
3. At present prices of commercial nitrogen, its application to permanent pastures has not been profitable. The stimulation of clovers by the application of mineral fertilizers provides increased grazing in the spring, and also leaves sufficient nitrogen in the soil to stimulate the succeeding grass crop.
4. The application of manure alone to permanent pastures produces small increases in the yield of beef, but a combination of superphosphate and manure very materially increased the yield of beef.
5. There is an evident direct relation between the amount of protein produced per acre and the beef yield per acre.
6. During the grazing season on permanent pastures, there are seasonal peaks of gain and carrying capacity, with corresponding periods of low gains and low-carrying capacity.
7. It is essential to provide supplementary grazing crops to fill out the periods of low grazing on permanent pastures in order to realize the greatest returns from fertilization of pastures.
8. Black medic and Johnson grass, grown in rotation are the best plants for supplementary pastures for this territory.
9. In a more intensive operation, such as dairy farming, small grains may be used in rotation with Johnson grass to provide supplementary grazing.

SHEARED SUGAR BEET SEED WITH SPECIAL REFERENCE TO NORMAL AND ABNORMAL GERMINATION[1]

Bion Tolman and Myron Stout[2]

SINGLE-GERMED sugar beet seed has long been sought by the sugar beet industry. Attempts to produce seed with only a single germ by the process of selection have made very little progress. Townsend and Rittue (7)[3] report the early efforts of workers in the U. S. Dept. of Agriculture along this line. Bordonos (2) reports that a single-germed beet seed has recently been developed in southern Russia by hybridizing with natural single-seeded types. However, there is no immediate prospect of single-germed seed being available to the commercial industry in this country.

Parallel with efforts to select single-germed seed, attempts have been made to "crack" the sugar beet seed ball into its component units. Palmer (3) reports that prior to 1900 some "cracked" seed from Germany was placed on the American market, but it did not give satisfactory results, and he proceeds to enumerate the difficulties encountered in the use of "cracked" seed, several of which were (a) some of the germs were destroyed in the cracking machine; (b) other germs were exposed and the function of the seed ball in regulating germination was destroyed; (c) it was impossible to crack the seed balls without ruining a large portion of the germs, unless many pieces were left with more than one germ, in which case the field had to be thinned as usual.

Tabentsky (5) reports the efforts of some Russian workers to break single-germed seeds out of the multiple-germed seed ball. He states that the structure of some seed balls was such that they broke up rather easily, while some others were so completely unified by sclerenchymatous tissue that attempts to break them into units were largely unsuccessful.

Recently, in the United States, there has been a revival of interest in shearing the seed ball into single-seeded units, and Bainer (1) has developed machinery to do this on a commercial scale. During the past two years the use of sheared seed has spread rapidly due to the labor-saving possibilities it offers, and the prospect that it may become an important factor in the ultimate mechanization of the sugar beet industry.

Because of the widespread use of sheared seed it becomes important to have a fundamental understanding of the functions of the pericarp tissue of the seed ball and what can and cannot be done with it without seriously interfering with those essential functions. The present report gives the results of blotter and soil tests with seed units recovered from sheared seed as compared with the germination of whole seed balls and with naked seeds removed from the locule of the seed ball.

---

[1]Contribution from Salt Lake City Field Laboratory, Division of Sugar Plant Investigations, Bureau of Plant Industry, Soils and Agricultural Engineering, U. S. Dept. of Agriculture. Received for publication April 29, 1944.

[2]Associate Agronomist and Assistant Physiologist, respectively.

[3]Figures in parenthesis refer to "Literature Cited", p. 759.

MATERIALS AND METHODS

These studies have dealt principally with three kinds of sheared seed units, *viz.*, (a) perfect sheared seed (seed units with one germ completely enclosed within the seed ball locule); (b) imperfect sheared seed (sheared seed where the locule has been broken and the true seed exposed); and (c) naked seeds (seeds completely freed from the nut-like seed ball locule). Sheared seed units with more than one germ have been avoided inasmuch as these do not represent conditions essentially different from normal seed balls. In all tests whole seed balls with all but one germ destroyed were used as a check to indicate normal performance.

Seeds were germinated on blotters in Petri plates and in soil in specially built germinators with glass sides which permitted periodic observations to determine both hypocotyl and radicle development. Germination was carried on at room temperature in the dark except when observations were being made. The germinators were tipped at an angle so that the hypocotyls grew against the glass on one side and the radicles grew against the glass on the other.

EXPERIMENTAL RESULTS

Sugar beet seed balls vary greatly in size, weight, and number of true seeds. Tests were conducted, using different seed lots, to determine the range of variability that occurs in commercial seed lots. The results of these tests are given in Table 1. The average number of sprouts per germinating seed ball varied from 1.42 to 2.37. Variability in the number of sprouts per ball is no doubt influenced by both variety and environmental factors. It is also evident that germination conditions influence the number of sprouts that develop from a seed ball. The germination percentages were higher under greenhouse conditions than from field plantings, and the average number of sprouts per ball also increased. Subsequent tests indicated that when soil moisture was varied under greenhouse conditions so as to reduce the total germination percentage, the average number of sprouts per ball was also reduced (Table 2). The data in Table 2 also gave a comparison of the number of sprouts per seed unit of sheared seed as compared with whole seed balls. These results add further evidence that the more favorable conditions are for germination, the greater will be the average number of sprouts per seed ball or seed unit.

TABLE 1.—*Average sprouts per seed ball of various lots of sugarbeet seed germinated under greenhouse and field conditions.*

Variety and source of seed tested	Planted in greenhouse		Planted in field	
	Germination, %*	Average number sprouts per germinating seed ball	Germination, %*	Average number sprouts per germinating seed ball
U. S. 22, Port Angeles, Wash. (9301)	92	1.94	73	1.75
U. S. 15, Klamath Falls, Ore. (9302)	70	1.42	56	1.35
U. S. 15, Medford, Ore. (9304)......	90	2.13	87	1.91
U. S. 200, Jefferson, Ore. (9307).....	97	2.37	87	2.08
U. S. 215, Jefferson, Ore. (9308).....	98	2.12	87	1.77
U. S. 33, Ogden Valley, Utah (9309)..	92	1.79	83	1.70

*Germination percentage is based on the number of seed balls or seed units producing one or more seedlings.

TABLE 2.—*Average sprouts per germinating seed unit of sheared seed and whole seed balls planted in the greenhouse under medium and high moisture conditions.*

Kind of seed tested	12.4% soil moisture		16.7% soil moisture	
	Germination, %	Average number sprouts per germinating seed unit	Germination, %	Average number sprouts per germinating seed unit
Whole seed balls......	70	1.68	80	2.00
Sheared seed.........	61	1.24	70	1.29

Further tests were conducted to compare the actual number of sprouts developing from a unit of sheared seed with the number of sprouts from whole seed balls. The results of these tests, planted in greenhouse soil, are given in Table 3. It is evident that inclusion of the sheared seed units, ranging in size from 9/64 to 10/64 inch, increased the average number of sprouts per seed unit. However, both lots of sheared seed show a striking increase in the percentage of seed units developing only one plant when compared with whole seed balls.

TABLE 3.—*Number of seedlings per germinating seed unit from sheared and whole seed planted in greenhouse soil.*

Kind of seed compared*	Percentage seed units producing				Av. No. sprouts per germinating seed unit
	1 seedling	2 seedlings	3 seedlings	4 seedlings	
Sheared seed, 7/64 to 9/64 inch in size.........................	77	21	2	0	1.25
Sheared seed, 7/64 to 10/64 inch in size......................	66	30	4	0	1.38
Whole seed balls (commercial seed)	33	56	10	1	1.78

*Germination of sheared seed was 92% on blotters and 74% in greenhouse soil. The germination of whole seed was 90% on blotters and 89% in greenhouse soil.

It should also be noted from these data that, contrary to popular belief, only 11% of the seed balls developed more than two seedlings.

One fact in these tests with the sheared seed was rather disturbing. This was that only 74% of the sheared seed units planted in soil produced seedlings, whereas 92% of the sheared seed units germinated on blotters. In view of this fact a rather critical examination of the sheared seed was made and it was found that it contained some naked seeds (true seeds removed from the seed ball locule), also that about 25% of the sheared seed units had been so broken in the shearing process that the true seed was exposed. Tests were then conducted in Petri dishes and in special glass germinators where the germination of naked seeds and partially exposed seeds could be closely observed. These tests included whole seed balls with one germ, perfect sheared seed, imperfect sheared seed, and three classes of naked seeds, *viz.*, (a) perfect naked seeds as determined under the binoculars, (b) naked seeds with small visible cracks in the testa, and (c) naked seeds with

the testa almost entirely removed (Fig. 1). The results of these tests are given in Table 4.

The data and observations indicate that there was no difference between the germination of perfect sheared seed and whole seed balls

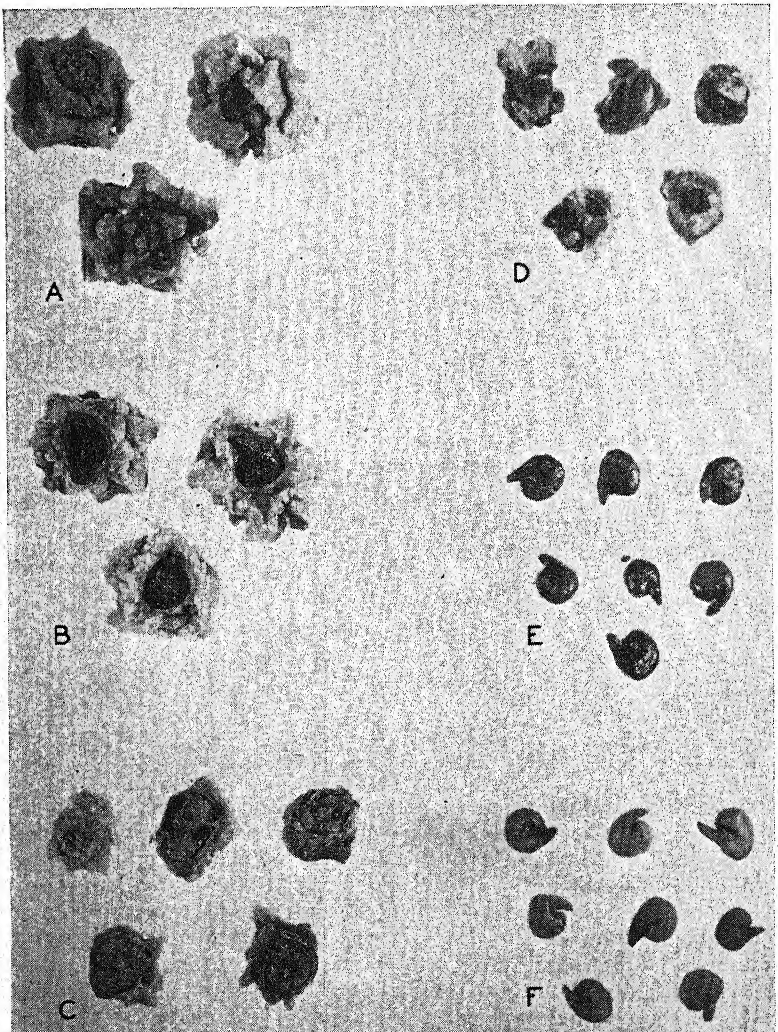


FIG. 1.—Types of sugar beet seeds used in studies. A, whole seed balls containing one true seed; B, whole seed balls with ovary cap removed to show the true seed in the seed locule; C, perfect sheared seed (one true seed completely enclosed in pericarp tissue); D, imperfect sheared seed (seed locule broken exposing true seed); E, perfect naked seeds (true seeds removed from the seed ball locule but still having both the inner and outer testa intact); and F, naked seeds with outer testa removed but with inner testa intact.

TABLE 4.—*Percentage normal and abnormal germination of perfect sheared and perfect naked sugar beet seeds as compared with imperfect sheared and imperfect naked sugar beet seeds when germinated on blotters.*

Kind of seed germinated	Abnormal germination*	Normal germination†
Perfect sheared seed	0	100
Imperfect sheared seed	60	40
Perfect naked seed	70	30
Naked seeds with testa broken	80	20
Naked seeds with testa almost entirely broken	95	5

*Abnormal germination indicated by cotyledons breaking away from reserve food supply before radicle shows any signs of development.
†Normal germination indicated by growth of the radicle while the cotyledons remain in contact with starchy perisperm.

with single germs. In both cases the radicle emerged, elongated, and developed root hairs, while the cotyledons remained within the locule, absorbing the reserve food supply of the perisperm. When the radicle had grown to a length of 1½ inches the cotyledons became detached from the seed ball and were in position to be pushed through the soil to the surface as the hypocotyl elongated (Fig. 2 and Table 5).

TABLE 5.—*Comparative rate of growth in mm of the radicle and hypocotyl of sugar beet seeds planted 3 inches deep in greenhouse soil.**

	Number of days after planting when measurements were taken			
	3rd day	4th day	5th day	6th day
Average length of radicles	14.8	24.6	29.2	32.6
Average length of hypocotyls	2.2	16.0	41.6	75.1
Increase in length of radicles	—	9.8	4.6	3.4
Increase in length of hypocotyls	—	12.8	25.6	33.5

*Measurements taken at 3, 4, 5, and 6 days after planting.

It was clearly evident, however, that many of the naked seeds and imperfect sheared seeds did not germinate normally. Abnormal germination occurred in from 60 to 90% of the seeds in these classes. In the main this abnormality of germination consisted in the breaking away of the cotyledons from the reserve food supply almost as soon as growth started. Frequently, the cotyledons opened up and the hypocotyl elongated as much as 1½ inches before the radicle showed any growth (Fig. 3). Subsequent soil tests indicated that this loss of reserve food greatly disturbed the growth potential and growth habit of the young seedling.

It was also evident that both the seed ball and the testa of the naked seed helped to control the progressive stages of germination.

In order to determine the effect of some of the noted abnormalities of germination on seedling growth in the soil, whole seed balls with one germ, perfect sheared seeds, imperfect sheared seeds, and perfect naked seeds were planted in soil at depths of ¼, ¾, 1¼, 2, and 3 inches. The soil containers had glass sides and the seeds were planted

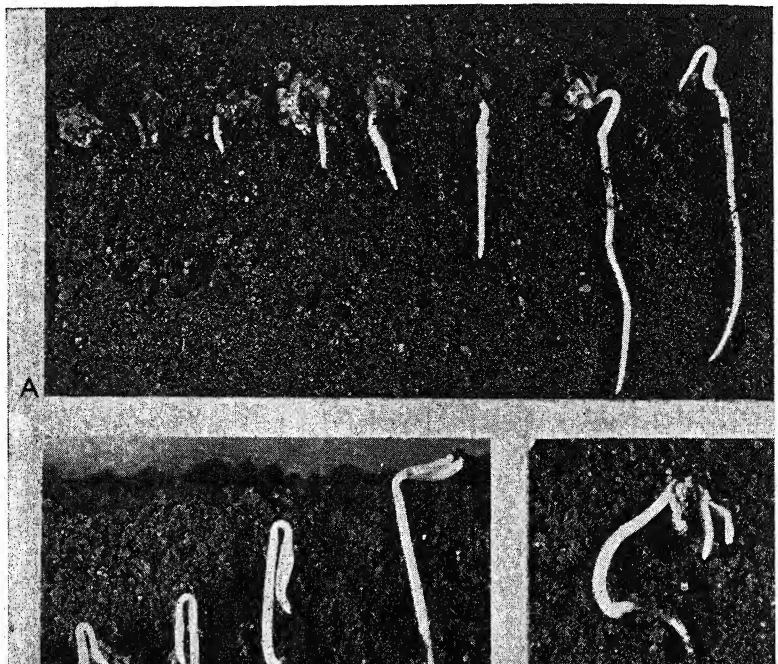


FIG. 2.—Stages in the germination of sugar beet seed. A, radicle begins development and lengthens rapidly until it is about 1½ inches long. During this period the cotyledons remain in the seed in contact with the white, starchy food reserve; B, hypocotyl begins growth and cotyledons are pulled from the seed and pushed up through the soil to the surface where they then begin manufacturing food. Note the development of root hairs and the sharp angle at which the cotyledons hang down so that they offer little resistance as they are pulled through the soil. C, Abnormal seedling. Cotyledons are difficult to push or pull through the soil while in this position. Note the bent hypocotyl. This seedling never reached the soil surface.

next to the glass so that germination and growth could be observed, and the soil was firmed moderately around the seed. The results of this test are shown in Table 6.

TABLE 6.—*Comparison of the percentage of seedlings emerging when whole, sheared, and naked seeds were planted at different depths in greenhouse soil.*

Kind of seed planted	Planting depth				
	¼ in.	¾ in.	1¼ in.	2 in.	3 in.
Whole seed balls, 1 germ......	92	88	87	92	90
Perfect sheared seed..........	90	92	88	90	88
Perfect naked seed............	90	33	8	0	0
Imperfect sheared seed........	85	42	25	8	13

There was good germination of the seed and 100% of the seedlings from the perfect sheared and whole seed balls reached the surface from the deepest planting. However, only a small percentage of the seedlings from the naked seeds and imperfect sheared seed reached the surface when the seed was planted ¾ inch or deeper. This was thought to be due to at least three factors, *viz.*, (a) reduced seedling vigor due to loss of reserve food supply; (b) mechanical difficulties due to the fact that the hypocotyl and cotyledons are not in a favorable position to be pushed up through the soil and the radicle is not firmly enough anchored in the soil so that a maximum of pressure can be exerted (Figs. 1C and 3); and (c) loss of growth hormone in the reserve food supply with a consequent loss of geotropic response. As a result of possibly the last two of these factors, the seedlings became bent and twisted in the soil and made little or no progress toward the soil surface.

As further evidence that seedlings from naked and imperfect sheared seeds which germinate abnormally do not have the soil penetrating power of normal seedlings, a test was run in which both depth of planting and firmness of the soil over the seed was varied. The results of this test are given in Table 7.

The results of this test indicate that if it were possible to plant the seed ½ inch or less in depth, that many of the abnormally germinating seedlings would emerge from the soil and develop into normal plants. Leaving the soil loose would also enable more seedlings to emerge. However, under field conditions, planting ½ inch or shallower would be unsafe, and the soil over the seed cannot be left loose without danger of excessive loss of soil moisture.

DISCUSSION

Knowledge that 20 to 25% of the sheared seed units have exposed seeds and that one-half or more of these will not produce a seedling when planted more than ½ inch deep offers an explanation of the discrepancy in the percentage germination of sheared seed when planted in soil as compared with the germination percentage on blotters.

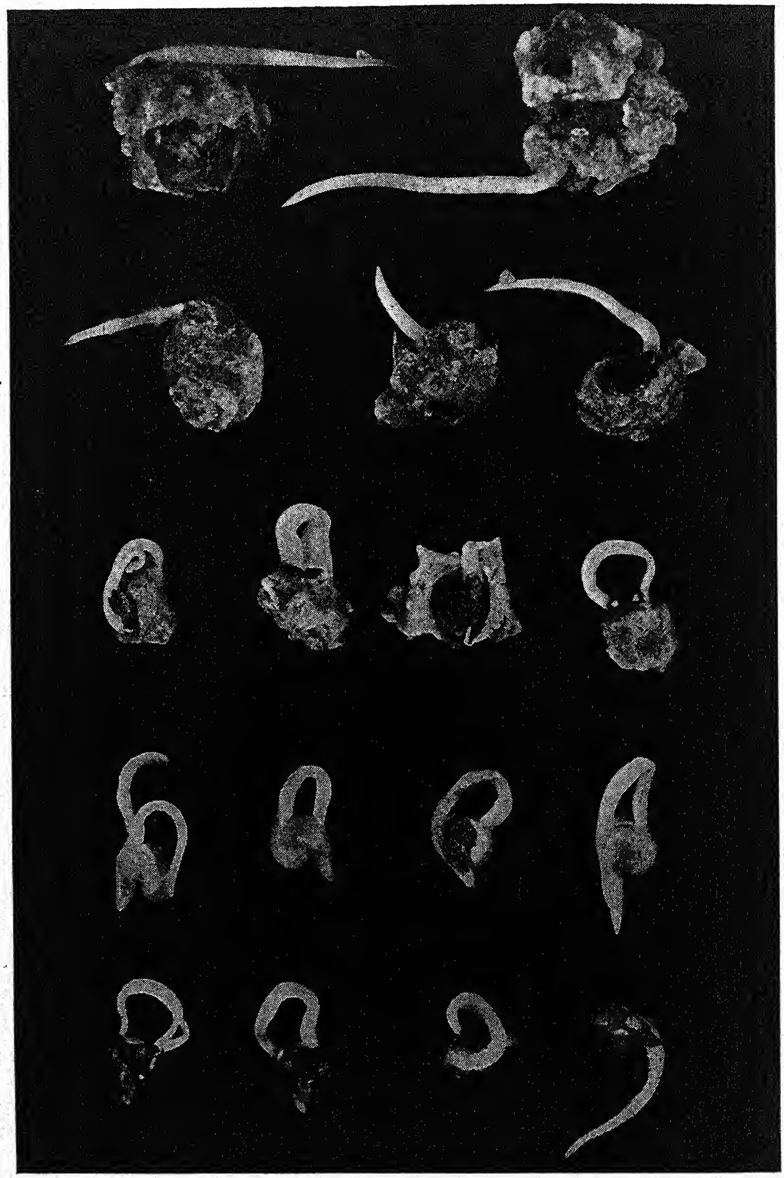


FIG. 3.—Germination of the various types of sugar beet seeds studied. From top to bottom the types are: 1, Whole seed balls containing one true seed; 2, perfect sheared seed; 3, imperfect sheared seed; 4, naked seeds with outer testa removed; 5, perfect naked seeds. In the first two types, germination is proceeding normally. In the last three types germination is generally abnormal as shown by the breaking away of the cotyledons from the reserve food supply before much, if any, growth of the radicle occurs.

TABLE 7.—*Comparison of the percentage of seedlings emerging when whole, sheared and naked seeds were planted at different depths in greenhouse soil of varying compactness.*

Firmness of seedbed*	Depth of planting				
	$\frac{1}{16}$ in.	¼ in.	½ in.	1 in.	2 in.
Whole Seed Balls, 1 Germ					
Soil packed	92	90	90	80	75
Soil firm	90	82	83	85	82
Soil soft	92	92	87	88	88
Perfect Sheared Seed					
Soil packed	80	87	88	82	75
Soil firm	88	83	82	78	75
Soil soft	85	85	88	83	80
Perfect Naked Seed					
Soil packed	97	75	33	0	0
Soil firm	97	87	50	8	0
Soil soft	100	93	75	25	0
Imperfect Sheared Seed					
Soil packed	75	42	42	17	8
Soil firm	82	67	50	25	8
Soil soft	87	75	67	25	17

*Compactness of seedbed was controlled by the amount of pressure applied to the soil placed over the seeds.

The tests reported in this paper indicate that for precise results, we should know the percentage of normal germinating seed units in each lot of sheared seed planted under field conditions. Pounds of seed to plant per acre should be controlled by the percentage of seed units germinating normally and not by the total germination as indicated by blotter test where abnormal and normal germination have not been differentiated.

Although the allowable variation in depth of planting is less in sheared seed than in whole seed (4), the optimum depth of planting must be the same in both cases. The optimum depth of planting for both whole seed and sheared seed is that they should be planted just as shallow as moisture will permit. Depth of planting should therefore be governed by soil moisture and not by kind of seed planted. The evidence indicates that a seedling from a perfect sheared seed will penetrate the soil just as far as will a seedling from a single-germed seed ball. This does not mean, however, that single seed units, whether they be sheared or whole seed balls, will emerge through the same depth of soil or exert the same pressure against a soil crust as will two or more seedlings from the same seed ball.

It should also be noted that there is a further grinding of the seed units in the seed drills and that there is no doubt an increase in the percentage of injured or imperfect seeds during the planting process. Improvement in drill design and in precision of manufacture will do

much to eliminate this phase of the problem. However, some work should no doubt be undertaken to determine the extent of seed injury by the drill mechanism.

Polishing sheared seed to make it more uniform in size has been tried. Attention should be given to the fact that any operation which tends to have a further grinding action on the seed units may injure or expose more of the true seeds and from this standpoint any such operation would be undesirable.

These studies also point out a problem in the uniform distribution of effective sheared seed units. At any given rate of seeding there will be skips where only sheared units with exposed seeds are planted. If enough seed units are planted to insure an adequate initial stand, some bunching of plants will occur in the spaces where perfect sheared seed units fall together.

Further work with sheared seed will no doubt do much toward solving the problems which still exist. However, in future studies it would seem desirable to compare critically the seedling distribution from whole seed and sheared seed planted at equivalent rates with precision planters. For years past, farmers and sugar company fieldmen have attempted to get a more favorable distribution of seedlings by cutting down seeding rates, and some farmers have established the practice of planting only 9 to 10 pounds of seed as compared to the 15 to 18 pounds generally used. In at least one area single-seed dropper drills were developed and used extensively. With the use of these drills satisfactory stands were obtained by planting 4 pounds of whole seed per acre. A description of these drills was recorded in 1942 and the possibilities of mechanically thinning the thin but uniformly spaced seedlings was pointed out (6).

Data presented in this paper show that 89% of the whole seed balls in commercial seed produce not more than two seedlings. This means that if seed balls were distributed singly at 2-inch intervals that 89% of the time there would not be more than two seedlings in a place. It is felt that this type of seedling distribution can be as successfully mechanically thinned as can sheared seed plantings if the spacing relationship to the increased number of doubles is properly considered. Larmer[4] has shown that doubles spaced 20 inches apart yield just as well as singles spaced 10 inches apart. With this principle in mind the whole problem of seedling distribution, from either whole seed or sheared seed, to mechanical thinning needs further consideration.

SUMMARY

A comparison of the germination of sheared sugar beet seed, whole seed balls, and naked seeds was made using blotters and soil in special glass germinators and also in the greenhouse bench. These tests showed that most naked seeds and 12 to 15% of the sheared seed germinated abnormally. This abnormal germination was evidenced by the fact that the cotyledons broke away from the starchy food

[4]Unpublished data by F. G. Larmer, formerly Assistant Pathologist, Division of Sugar Plant Investigations, Bureau of Plant Industry and Soils, Agricultural Research Administration, U. S. Dept. of Agriculture.

reserve during the initial stages of germination and before the radicle had developed and become established. The cotyledons did not remain in a position to be pushed through the soil and there was also apparent some loss in geotropic response. As a result of these abnormalities very few seedlings from naked seeds and imperfect sheared seeds emerged from the soil when planted more than ½ inch deep. It was evident that blotter germination tests gave an erroneous impression of the percentage of seed recovered in the shearing process, unless care was taken to differentiate between normal and abnormal germination.

LITERATURE CITED

1. BAINER, ROY. Sheared sugar beet seed investigations. Spreckels Sugar Beet Bul., 6. 1942.
2. BORDONOS, M. G. Unilocular types of sugar beets. Proc. Lenin All-Union Acad. Agr. Sci., 11:3–4. 1941. (Translation by Eugenia Artschwager.)
3. PALMER, TRUMAN G. Sugar Beet Seed—History and Development. New York: John Wiley & Sons. 1918.
4. PRICE, CHARLES. Depth of planting tests with sheared and whole sugar beet seed. Spreckels Sugar Beet Bulletin, 7 (4):17. 1943.
5. TABENTSKY, A. A. Anatomy of sugar beets. Sveklovodstvo (The Sugar Beet Industry), All-Union Inst. of Sugar Beet Res., 1(2):104–105. 1940. (Translation by Eugenia Artschwager.)
6. TOLMAN, BION, and MURPHY, ALBERT M. Sugar beet culture in the intermountain area with curly-top resistant varieties. U. S. D. A. Farmers' Bul. 1903. 1942.
7. TOWNSEND, C. O., and RITTUE, E. C. The development of single-germ beet seed. U. S. D. A. Bur. Plant Ind. Bul. 73. 1905.

PLANT CULTURE AND OTHER STUDIES WITH SOME GUANIDINE COMPOUNDS[1]

BAILEY E. BROWN[2]

DURING recent years many new compounds, both inorganic and organic, have been proposed for fertilizer use. Almost all of these compounds at one time or another have been subjected to tests against standard fertilizer materials to determine their nutrient value for different crop plants. Some have qualified; some have not. Many of the comparative studies have been made in the greenhouse, in pots, or beds; others, under field conditions.

In this article the results of greenhouse and laboratory studies on certain guanidine compounds are reported. The studies were made to determine (a) the nutrient value of di-guanidine phosphate, tri-guanidine phosphate, tri-guanidine sulfate, and dicyanodiamide toward certain indicator crop plants—millet, oats, and wheat—in soil tests; and (b) the degree of ammonification and nitrification the compounds would undergo under controlled conditions.

RESULTS REPORTED BY OTHER INVESTIGATORS

Studies to determine the nutrient value of guanidine compounds, particularly those with which this paper is concerned, appear to have been few and far between, and the results obtained therefrom are more or less conflicting. Guanidine, $NH:C(NH_2)_2$, is a strong base and, when pure, has a nitrogen content of 71.15%. It was prepared first by Strecker in 1861 by oxidation of guanine $C_5H_5ON_5$, but is now more commonly prepared by heating dicyanodiamide with an ammonium salt. Guanidine and its salts were first shown to be injurious to plants by Kawakita (7)[3] and soon thereafter by Schreiner, *et al.* (10) in the laboratories of the Bureau of Soils, U. S. Dept. of Agriculture. Hutchinson and Miller (4) found by means of water culture tests with peas that guanidine hydrochloride, concentration of 80 p.p.m. nitrogen, was not toxic but was used only scantily as the sole source of nitrogen.

Schreiner and Skinner (11), also employing solution cultures, studied the effect of guanidine carbonate on several indicator crop plants, including corn, cowpeas, potatoes, and wheat, and reported that this compound, at a concentration of 12 p.p.m. nitrogen, was injurious in the presence of nitrate, but no injury was found in cultures devoid of nitrate. They stated, "The plant is normal for a few days then begins to show a spotted appearance on leaf and stem. This effect develops until the plant is bleached to a considerable extent, with final collapse. This harmful effect of guanidine on plants is augmented by the presence of nitrate and increases with the amount of nitrate present. Sources of nitrogen, other than nitrate, did not show this same effect."

A number of investigators have worked with guanidine nitrate. Wagner (13) conducted pot experiments, as did Hiltner (3). Wagner reported that guanidine nitrate gave only a slight yield increase of oats in comparison with urea nitrate and sodium nitrate. Hiltner reported that in one year guanidine nitrate had a toxic effect on oats, but to a considerable extent increased the yield of mustard.

---

[1]Contribution from the Division of Fruit and Vegetable Crops and Diseases, Bureau of Plant Industry, Soils, and Agricultural Engineering, Agricultural Research Administration, U. S. Dept. of Agriculture. The guanidine compounds under comparison were prepared by the Department of Chemical Engineering, Tennessee Valley Authority, at Wilson Dam, Ala. Dr. Walter H. MacIntire of the Tennessee Agricultural Experiment Station, enlisted the cooperation of the U. S. Dept. of Agriculture and other agencies to have the materials tested. The writer wishes to acknowledge the helpful cooperation of Dr. MacIntire during the course of the experimental studies. Received for publication May 12, 1944.

[2]Senior Biochemist.

[3]Figures in parenthesis refer to "Literature Cited", p. 767.

This investigator decided from his studies that a marked residual effect existed in the year following the application of guanidine nitrate.

Hazelhoff, *et al.* (2), as a result of 5 years of study, stated that both guanidine nitrate and guanidine carbonate were inferior to standard nitrate or ammonium compounds. Kappen (6) found that the effect of guanidine nitrate on mustard was practically *nil*, but that there was a marked residual effect.

Lewis (8) presented some interesting results on guanidine carbonate, guanidine nitrate, guanidine phosphate, urea phosphate, phospham (PN_2H), and phosphorus nitride (P_2N_5). According to this investigator, "Guanidine salts were slower in their action than were ammonium and urea salts. Guanidine gave greater increases in yields of barley and mustard on neutral than on acid soils. In contrast with much of the published literature, no direct evidence was obtained of any toxic effects of guanidine salts, but the fact that guanidine nitrate, over a quarter of the nitrogen of which is in the nitrate form, did not increase the first crop yield of mustard on neutral soil is suggestive. This lack of response to guanidine nitrate may have been due to a depressing effect of guanidine on nitrification in the early stages. Guanidine salts may prove useful where a slow-acting form of nitrogen is required."

No reference to di-guanidine sulfate, and only an occasional one to dicyanodiamide ($C_2H_4N_4$), was to be found in the agricultural literature. Allison, *et al.* (1) reported the cowpea plant much less tolerant to dicyanodiamide than was wheat on two soil types, *viz.*, Norfolk sandy loam and Chester loam. Schutt (12), experimenting on eight soil types and five different cultivated plants over a period of 2 years, stated that even a fairly high dicyanodiamide concentration in calcium cyanamide caused no injury to the plants. Only with the addition of 10% or more of dicyanodiamide nitrogen was there injury to the plants and reduction in crop yields. A later report by Schutt (12) indicated a similar trend. Murata (9), reporting the results of ammonification studies with dicyanodiamide, states that the practical value of dicyanodiamide for paddy rice is not great because it is not absorbed by the soil and is but slowly ammonified, so that it is likely to be lost in the drainage before it can be utilized.

Jacob, *et al.* (5) carried on an important series of investigations on the transformation of cyanamid and related compounds, including dicyanodiamide, under controlled cultural conditions and reported that, "dicyanodiamide when added to soil slowly disappeared, more than one-half being decomposed during a period of two months", and that, "the nitrogen accumulated in the soil as ammonia which was not readily nitrified." It is of further interest to note their statement that, "in all cases where dicyanodiamide was applied the nitrate formation from the soil organic matter was markedly retarded", and that, "the nitrification of ammonium sulfate in the presence of dicyanodiamide was prevented for a period of 210 days where the dicyanodiamide was used at the rate of 10.5 mgm for 100 grams of soil". These investigators present a review of the literature up to 1924, the consensus of which indicates that while the nitrogen of dicyanodiamide may be converted to ammonia the latter tends to accumulate in the soil and is only slowly nitrified even under optimum conditions.

OUTLINE OF PRESENT STUDIES

The tabulation below gives the materials employed in the various pot-culture studies and their composition in terms of nitrogen (N) and phosphoric acid (P_2O_5):

Materials used	Nitrogen, %	P_2O_5, %
Di-guanidine phosphate, $(CH_5N_3)_2\ H_3PO_4$	38.79	33.08
Tri-guanidine phosphate, $(CH_5N_3)_3\ H_3PO_4$	45.36	26.07
Di-guanidine sulfate, $(CH_5H_3)_2\ H_2SO_4$	38.70	——
Dicyanodiamide, $C_2H_4N_4$	60.05	——
Urea, $CO(NH_2)_2$	46.00	——
Ammonium sulfate	21.20	——
Sodium nitrate	16.17	——
Dried blood	13.51	——
Triple superphosphate	——	46.71

The main interest of the investigators of the Tennessee Valley Authority centered in di- and tri-guanidine phosphates, and the di-guanidine sulfate and dicyanodiamide were included in the tests chiefly as subsidiary compounds for comparative purposes. In the greenhouse tests reported herein, ammonium sulfate, sodium nitrate, dried blood, and urea were employed as standard nitrogen sources; triple superphosphate as the source of P_2O_5; and sulfate of potash as the source of K_2O.

The greenhouse studies, comparing the guanidine compounds and dicyanodiamide, were conducted in 1-gallon glazed pots, holding 5.5 kilograms of soil. Details of the greenhouse tests are as follows:

1. Soil used: Norfolk loamy fine sand (Va.) pH 4.8
2. Fertilizer analyses used: 0-8-8, 2-8-8, 4-8-8, 6-8-8, and 8-8-8. These provided for 0, 2, 4, 6, and 8% of nitrogen, with constant P_2O_5 and K_2O additions throughout.
3. Nitrogen derived from guanidine compounds and other sources previously mentioned.
4. Phosphoric acid (P_2O_5) derived from the di- and tri-guanidine phosphates and triple superphosphate (46.71% P_2O_5) added to make up for any lack of P_2O_5 in the two guanidine phosphates.
5. Potash (K_2O) derived from potassium sulfate (48% K_2O).
6. Rate of fertilizer application throughout: 2,000 pounds per acre.
7. Rate of nitrogen application: 0, 40, 80, 120, and 160 pounds per acre.
8. Rate of other fertilizer constituents: P_2O_5 and K_2O, each 160 pounds per acre.
9. To all pots magnesium sulfate (Kieserite) was added at the rate of 30 pounds of magnesium oxide (MgO) per acre.
10. Method of applying fertilizer: Mixed with total quantity of soil by means of a mechanical mixer.

Other details connected with the pot-culture studies included:

1. Crop-plant indicators grown: German millet, oats, and wheat.
2. Number of plants per pot: 10 (final stand in each pot).
3. Number of replications, 3; a total of 30 plants per treatment.

RESULTS OF POT-CULTURE TESTS

The results of two pot tests with German millet and one test each with oats and wheat are given in Table 1. In these four tests the nitrogen of the standard fertilizer mixtures was derived from (a) urea and (b) a mixture of ammonium sulfate, sodium nitrate, and dried blood (60-20-20 ratio). Urea was selected as an individual source of of nitrogen because of its close relationship to the guanidine compounds, as well as to dicyanodiamide.

From the results presented in Table 1 for German millet, it will be noted that:

1. The soil used (Norfolk loamy fine sand) responded markedly to nitrogen fertilization.

2. When dicyanodiamide was the nitrogen source, yields were in all but two cases lower than the checks receiving no nitrogen. Dicyanodiamide in almost all other reported tests has generally been found toxic to plants.

TABLE 1.—*Results with German millet, oats, and wheat obtained in pot-culture tests comparing guanidine compounds with standard nitrogen fertilizers.**

Sources of nitrogen in nutrient mixture	Analysis of mixture	Test 1		Test 2		Test 3		Test 4	
		Dry weight of millet plants		Dry weight of millet plants		Dry weight of oat plants		Dry weight of wheat plants	
		Actual, grams	Relative	Actual, grams	Relative	Actual, grams	Relative	Actual, grams	Relative
No nitrogen (P-K)	0–8–8	12.1	100.0†	14.7	100.0†	7.5	100.0†	7.7	100†
Di-guanidine phosphate	2–8–8	20.5	170.0	26.3	179.0	15.7	209.0	12.2	158.0
	4–8–8	20.7	171.0	25.3	172.0	24.2	323.0	20.9	271.0
	6–8–8	13.4	110.7	14.1	96.0	13.8	184.0	11.6	151.0
	8–8–8	9.9	81.8	10.9	74.1	9.2	123.0	8.2	107.0
Tri-guanidine phosphate	2–8–8	19.3	160.0	24.0	163.2	10.2	136.0	9.9	129.0
	4–8–8	18.6	154.5	21.0	142.8	22.5	300.0	18.7	243.0
	6–8–8	14.8	122.3	18.4	125.2	18.2	242.0	16.0	208.0
	8–8–8	11.9	98.3	10.5	71.0	10.1	135.0	8.9	116.0
Di-guanidine sulfate	2–8–8	19.6	162.0	26.0	177.0	13.4	179.0	12.8	166.0
	4–8–8	20.7	171.0	22.9	155.8	21.8	290.0	20.1	261.0
	6–8–8	15.4	127.3	16.3	110.9	14.5	193.0	13.7	178.0
	8–8–8	8.8	72.7	11.5	79.8	8.1	108.0	7.7	100.0
Dicyanodiamide	2–8–8	9.9	81.8	12.3	83.7	7.5	100.0	7.2	94.0
	4–8–8	10.9	90.0	11.9	81.0	9.9	132.0	8.9	116.0
	6–8–8	9.9	81.8	11.4	77.5	7.6	101.0	7.3	95.0
	8–8–8	7.8	64.5	9.0	61.3	6.7	89.0	5.9	77.0
Urea	2–8–8	23.0	190.0	31.5	214.3	17.5	233.0	17.0	221.0
	4–8–8	29.0	240.0	34.0	231.3	24.2	323.0	22.0	286.0
	6–8–8	32.0	264.5	36.5	248.3	22.5	300.0	23.1	300.0
	8–8–8	31.2	258.0	36.0	245.0	21.4	285.0	22.9	297.0
Ammon. sulfate, sodium nitrate, dried blood	2–8–8	21.1	174.4	29.8	202.7	18.0	240.0	17.8	231.0
	4–8–8	27.7	229.0	32.1	218.4	23.3	311.0	22.2	289.0
	6–8–8	30.2	249.6	36.5	248.3	23.9	319.0	24.0	311.0
	8–8–8	28.6	221.6	35.6	242.2	21.6	288.0	20.8	270.0

*Tests made on Norfolk loamy fine sand (pH 4.8).
†P-K mixture at 100.

3. The guanidine compounds made a good showing in the lower concentrations. The 2% nitrogen (2–8–8) mixtures in comparison with the no-nitrogen mixture (0–8–8) gave comparatively high yields of millet, although generally lower than when similar amounts of nitrogen were added as urea or the mixed sources.

4. With an increase of nitrogen to 4% (4–8–8 mixture), the millet weights showed only slight changes from the 2% nitrogen mixtures.

5. With additional nitrogen increases from the guanidine compounds and dicyanodiamide (6–8–8 and 8–8–8 mixtures), the millet yields dropped off drastically, whereas the yields were greater when the standard nitrogen sources were employed.

6. Referring again to the results of the dicyanodiamide mixtures, it is clear that no matter what the nitrogen concentration was, there was very little difference in the weights of millet obtained. It may be reasonable to assume that dicyanodiamide was either directly toxic to the millet or perhaps inhibited bacterial activities to such an extent that the nitrogen of the dicyanodiamide was not rendered available. It is more likely that both factors contributed to the low millet yields obtained with this source of nitrogen.

7. The results of tests 3 and 4 on oats and wheat (Table 1) follow the same general pattern as shown by the millet (tests 1 and 2) in that all the 2% and 4% mixtures (2–8–8 and 4–8–8), especially the latter rate, regardless of the nitrogen source, gave an increase in yield over the no-nitrogen mixture (0–8–8) mixture. With increasing rates of nitrogen, however, declining oat and wheat yields followed a trend shown by the millet results. This decline became very pronounced when the nitrogen content was brought to 8%, the yields from this rate approximating the weights of the no-nitrogen controls.

8. In tests 3 and 4 with oats and wheat, dicyanodiamide again proved ineffective, as every rate of nitrogen derived from it lowered the plant weights close to or lower than those of the no-nitrogen control.

9. The urea and the ammonium sulfate-sodium nitrate-dried blood mixtures gave results that were in harmony with those of tests 1 and 2 (Table 1).

EFFECT OF LIMING ON EFFICIENCY OF GUANIDINE COMPOUNDS

Since the results presented in Table 1 were obtained on a fairly acid soil, pH 4.8, the question arose, How would these organic compounds act in a less acid soil? Accordingly, a single test was run, using soil at two levels of acidity, pH 4.8 and pH 6.5[4]. Not all the treatments run in Table 1 were included in this test. The combination with 6% nitrogen (6–8–8) alone was tested. The results are shown in Table 2.

The results tend to show that the effect of liming was beneficial in that the guanidine compounds were rendered more efficient as a nitrogen sources for millet. Lewis (8), working with barley and mustard, states, "The barley and mustard results show that nitrogen applied in the form of guanidine was slow-acting but was more rapid in action on neutral than on acid soils".

[4]Change from 4.8 effected by treating acid soil with finely ground limestone, aqout 3,000 pounds per acre.

TABLE 2.—*Effect of liming on efficiency of guanidine compounds.*

Nitrogen source*	Dry weight in grams of German millet (30 plants)	
	On limed soil	On unlimed soil
Di-guanidine phosphate	21.2	10.4
Tri-guanidine phosphate	19.4	9.0
Di-guanidine sulfate	14.6	8.3
Dicyanodiamide	12.8	7.5
Urea	32.8	30.0
Ammon. sulfate-sodium nitrate-dried blood	29.6	29.3
No nitrogen (P-K)	9.8	7.5

*6% nitrogen.

AMMONIFICATION AND NITRIFICATION TESTS[5]

In view of the apparent inertness of the organic compounds as nutrient materials some preliminary studies were made to check their ammonification and nitrification behavior under laboratory conditions.

Duplicate flasks containing 25 grams of Keyport clay loam (pH 4.8) and 100 milliliters of tap water, together with certain quantities of materials to be tested, were incubated for 7 days, after which NH_3 was distilled off by MgO. The results are given in Table 3.

TABLE 3.—*Ammonification behavior of guanidine materials under laboratory conditions.*

Material	Mgs N in material added	Mgs N obtained per per flask, average	Av. mgs N deviation from check
Di-guanidine phosphate	60.0	7.5	+6.1
Tri-guanidine phosphate	60.0	3.9	+2.5
Di-guanidine sulfate	60.0	2.2	+0.8
Dicyanodiamide	60.0	1.5	+0.1
Casein	60.0	43.2	+41.8
Cottonseed meal	60.0	13.5	+12.1
Control	0	1.4	—

The results of the ammonification tests appear to show that the guanidine compounds and dicyanodiamide are not easily broken down, the di-guanidine phosphate being attacked more than the others.

In making the nitrification tests, 100 grams of Keyport clay loam containing 50 grams of $CaCO_3$ were incubated 30 days under optimum conditions. The nitrate determination was made by the zinc-copper couple method. The test was made in duplicate. Results obtained are given in Table 4.

The nitrification tests were not altogether satisfactory in that the

[5]These tests were made in the Division of Soil Microbiology under the direction of N. R. Smith whose helpful cooperation is gratefully acknowledged.

amount of nitrate nitrogen obtained from ammonium sulfate was somewhat lower than usual and that from the control was higher. However, these tests are fairly definite in showing that these compounds are not nitrified in the soil, but have a depressing effect on nitrification. This confirms the results obtained by Jacob, *et al.* (5, page 54) on the nitrification of dicyanodiamide, although in solution cultures, as in the ammonification tests, there is the possibility that it may be slightly ammonified. Whether the guanidine compounds might have been nitrified more extensively had they remained longer in contact with the soil was not determined.

TABLE 4.—*Nitrification tests with guanidine materials under laboratory conditions.*

Material	Mgs N in material added	Mgs N recovered per 100 grams soil	Mgs N deviation from control
Di-guanidine phosphate......	30	1.8	− 7.2
Tri-guanidine phosphate......	30	1.8	− 7.2
Di-guanidine sulfate.........	30	1.8	− 7.2
Dicyanodiamide.............	30	2.4	− 6.6
Ammonium sulfate..........	30	21.0	+12.0
Control....................	0	9.0	—

SUMMARY

Greenhouse pot-culture studies to determine the nutrient value of di-guanidine phosphate, tri-guanidine phosphate, di-guanidine sulfate, and dicyanodiamide, which have been suggested as possibly possessing fertilizer value, have been made. Pot-culture experiments were conducted with millet (German), oats, and wheat. The guanidine salts were employed in the greenhouse studies in different quantities, namely, 40, 80, 120, and 160 pounds per acre in 2–8–8, 4–8–8, 6–8–8, and 8–8–8 nutrient mixtures.

Compared with the control (no-nitrogen mixture, 0–8–8), the nitrogen of the guanidine compounds proved to be fairly effective at the 40- and 80-pound rates, but lowered the yields of all indicator crop plants when stepped up to 120 and 160 pounds of nitrogen per acre. These findings indicate that any attempt to use the guanidine salts as nitrogen sources would have to be made cautiously and limited to probably not more than 80 pounds of nitrogen per acre.

In comparing the millet, oats, and wheat yields obtained with the guanidine salts with those from the urea and the ammonium sulfate-sodium nitrate-dried blood mixtures, the guanidine compounds generally were less effective throughout than the standard nitrogen sources. The guanidine salts gave greater increases in yields of millet on close-to-neutral soils than on distinctly acid soil. With respect to dicyanodiamide, nothing favorable can be ascribed to it as a source of nitrogen on the basis of findings in these tests. Throughout the plant tests in the greenhouse it made a poor showing, with indications of a toxic action toward the indicator plants as evidenced by a bleached-out or chlorotic appearance. It is also conceivable that bacterial

action might have been inhibited so that the nitrogen of the dicyanodiamide was not rendered available in time to be of any nutrient use to the plants grown. The latter hypothesis is supported by both the ammonification and nitrification studies, which tend to show that the guanidine compounds and dicyanodiamide were not easily broken down. Of the different compounds the di-guanidine phosphate was the least resistant to change.

LITERATURE CITED

1. ALLISON, F. E., SKINNER, J. J., and REID, F. R. Toxicity studies with dicyanodiamide on plants. Jour. Agr. Res., 30:419–429. 1925.
2. HASELHOFF, H., LIEHR, C., and FLUHRER, K. Versuche mit Stickstoffdüngern. Landw. Vers. Sta., 100:37. 1922.
3. HILTNER, L. Über die in Bayern in den Jahren 1912 und 1913 bei Schneeglockchen, Flieder und winterroggen gemachten phänologischen Beobachtungen. Praktische Blätter für Pflanzenbau und Pflanzenschutz, 18:1–6. 1915.
4. HUTCHINSON, H. B., and MILLER, N. H. J. The direct assimilation of inorganic and organic forms of nitrogen in higher plants. Centr. f. Bakt., 30:513. 1911.
5. JACOB, K. D., ALLISON, F. E., and BRÂHAM, J. M. Chemical and biological studies with cyanamid and some of its transformation products. Jour. Agr. Res., 28:37–69. 1924.
6. KAPPEN, H. Düngungscersuch mit Umwandlungsprodukten des Kalkstickstoffs. Landw. Vers. Sta., 86:115. 1915.
7. KAWAKITA, T. Behavior of guanidine to plants. Bul Col. Agr. Tokyo, 6:181. 1904.
8. LEWIS, A. H. The fertilizer value of some concentrated materials, particularly urea and guanidine and their nitrates and phosphates. Jour. Agr. Sci., 26:509–526. 1936.
9. MURATA, H. Ammonification of dicyanodiamide and its derivatives in soil. Trans. Third Com. Int. Soc. Soil Sci., A:137–139. 1939.
10. SCHREINER, O., REED, H. S., and SKINNER, J. J. Certain organic constituents of soils in relation to soil fertility. U. S. D. A. Bul. 47. 1907.
11. ————, and SKINNER, J. J. Nitrogenous soil constituents and their bearing on soil fertility. U. S. D. A. Bur. Soils Bul. 87. 1912.
12. SCHUTT, L. The question of the action of dicyanodiamide on the growth of plants. Forschungsdieust, Sonderheft, 6:248–258. 1937.
13. WAGNER, P., Versuche über den wirkungswert des Salpetersauren guanidins und des Salpetersauren Harnstoffs im Vergleich zu Salpetersauren natron und Ammonitrat. Mitt. der Deutschen Landwirt., Gesellschaft, 29:417–421. 1914.

CHARACTERISTICS AND ORIGIN OF BLACKHULL WHEATS[1]

E. G. HEYNE AND L. P. REITZ[2]

APPROXIMATELY one-third of the Kansas wheat acreage in the decade ending with 1939 was planted with varieties developed by Earl G. Clark, a private wheat breeder and farmer living near Sedgwick, Kans. He became interested in wheat improvement when, as a boy of 15, he found three black heads of wheat in a field of Turkey. The seeds from these were increased and distributed as Blackhull wheat in 1917. This represented the foundation of Mr. Clark's wheat improvement work, and since that time he has distributed five other varieties related to Blackhull, *viz.*, Superhard (Blackhull), Clarkan, Kanhull, Chiefkan, and Red Chief. Blackhull, the most widely distributed variety of this group, was grown also in other states. The estimated acreage of this variety in the United States in 1939 was more than 8 million acres (7).[3] Early Blackhull also belongs in this group of varieties and is a selection out of Blackhull made by A. P. Haeberle, a farmer of Clearwater, Kans. Early Blackhull is grown at the present time on a considerable acreage in southwest Kansas and in parts of Oklahoma and Texas. It is the purpose of this paper to trace the development and to indicate the merits and weaknesses of each variety of the group.

Mr. Clark's methods are of interest because of the results obtained with limited material and equipment. Plant breeding has been referred to as an art as well as a science, and Mr. Clark apparently has used artistic talent effectively. All Blackhull wheats are visually attractive because of such characteristics as strong straw, bright plump grain, and attractive chaff color. He has depended on variations that occurred naturally due, presumably, in most cases, to natural hybridization. Spaced plantings have been used to some extent, but much of the actual selection work has been from field-planted material. This has been accompanied and followed by careful selection of large dark hard kernels by cleaning devices and by hand. Test plots have been maintained from which preliminary yield data were obtained. These, for the most part, consisted of single long rows.

Descriptions and some data have been published about this group of varieties, especially Blackhull (4, 17). Mr. Clark yearly has issued circulars describing his wheats. Technical descriptions of them, except Red Chief, have been published by Clark and Bayles (5, 6). However, most of the information concerning them is scattered through many publications, some of which are not generally available. For that reason a few statements concerning the origin and time of distribution of each variety will be given here.

---

[1]Contribution from the Division of Cereal Crops and Diseases, Bureau of Plant Industry, Soils, and Agricultural Engineering, Agricultural Research Administration, U. S. Dept. of Agriculture, and the Department of Agronomy, Kansas Agricultural Experiment Station, Manhattan, Kans. Contribution No. 359 from the Department of Agronomy. Received for publication May 24, 1944.

[2]Assistant Agronomist, Division of Cereal Crops and Diseases, and Associate Agronomist, Kansas Agricultural Experiment Station, respectively.

[3]Figures in parenthesis refer to "Literature Cited", p. 777.

BLACKHULL (C. I. 6251)

Blackhull originated from three black heads found in a field of Turkey wheat in 1912. The seed used for this field had been introduced from Russia to Harvey County, Kans., about 1906. This Turkey wheat had both red and black chaffed mixtures in it. The seed from the three black heads was planted and increased and the first distribution of Blackhull was made in the fall of 1917. Blackhull is a bearded winter wheat having earlier maturity, softer kernel, and a higher test weight than Turkey. The glumes of Blackhull generally have black stripes on the surface and under certain conditions are almost entirely black. The original Blackhull as distributed contained a few plants that had red instead of black markings on the glumes.

EARLY BLACKHULL (C. I. 8856)

Early Blackhull was selected from a field of Blackhull in 1921 by A. P. Haeberle of Clearwater, Kans[4]. This variety did not become important on farms until after 1930. Early Blackhull is a bearded variety and has the black stripes on the glumes like Blackhull. As its name indicates, it is an early-maturing wheat, being about 8 days earlier than Blackhull and 10 days earlier than Turkey. The straw is fairly short but lodges easily. The kernel is rather large and irregular in shape. The test weight is about the same as Blackhull. Because of its earliness it hastens the beginning of harvest which, with the planting of other later-maturing varieties, extends the harvest period and, hence, Early Blackhull is popular with farmers who have large acreages of wheat. It is not a very winter-hardy variety.

SUPERHARD (C. I. 8054)

Superhard is a selection from Blackhull made in 1920. The hardest and best looking kernels were selected, space-planted, and the progeny of individual plants studied in 1921. Only 70 selections were saved from the original 250 kernels. One selection appeared especially promising in 1922 because of its dark color and hard grain and was increased and distributed in the fall of 1925. Superhard is a bearded wheat and generally cannot be distinguished from Blackhull when growing in the field. However, under certain conditions, the grain can be distinguished when both varieties are grown together. Superhard has a harder kernel which does not bleach so readily as Blackhull.

CLARKAN (C. I. 8858)

In 1916 a natural hybrid between Blackhull and a beardless soft wheat (probably Harvest Queen) was found by Mr. Clark. From this natural cross only the beardless types were saved, particularly black beardless types with hard grain. In 1921, from this material was separated a soft wheat that was beardless and had white glumes. This soft beardless selection was tested, increased, and distributed in the fall of 1934 as Clarkan. Clarkan is a soft red winter wheat, tall and rather late but produces grain of high test weight.

KANHULL (C. I. 11877)

In 1926, 500 beardless head selections were made from Superhard. These evidently were natural crosses between Superhard and beardless selections saved in previous years from the Blackhull×soft wheat natural cross. One of the selections was similar to Blackhull except that it was beardless and slightly later. This selection was distributed as Kanhull in the fall of 1935.

CHIEFKAN (C. I. 11754)

From the same 500 head selections from which Kanhull was selected there were some heads with extra dark hard grain. One of these was increased and distributed in the fall of 1935 as Chiefkan. Chiefkan is a beardless hard winter

[4]In a letter dated May 9, 1944, Mr. Haeberle stated "Early Blackhull is a cross of regular Blackhull wheat and spring Marquis."

wheat with a fairly long slender head, black-striped glumes, and large grain with high test weight, higher than in other Blackhull wheats developed up to that time.

RED CHIEF (C. I. 12109)

An outstanding red-glumed beardless plant was found growing in a very poor spot in the middle of a field of Blackhull wheat. The plant had many tillers and was more erect and vigorous growing than the surrounding Blackhull plants. It produced 280 grains. The seed from this plant was increased and distributed as Red Chief in 1940. Red Chief may be the progeny of a natural cross between some of Mr. Clark's beardless wheat selections and the red-chaffed mixture that was present in Blackhull. Red Chief is similar in appearance to Chiefkan, but has red glumes striped with black instead of white glumes striped with black. The grain is darker in color and does not bleach as readily in the field and has a test weight equal to or higher than Chiefkan.

TEST WEIGHT

The most widely recognized characteristic of the Blackhull wheats is the high test weight possessed by all of the selections in the group. Turkey wheat apparently is the original source of at least part of the genes in all the Blackhull wheats, but these wheats all exceed Turkey in test weight, as shown in Table 1. Kanhull was grown only a few times in tests conducted by the Kansas Agricultural Experiment Station because of its low yield and weak straw but in the two comparisons shown, the test weight exceeded Turkey. Red Chief appears to have the highest test weight. However, in the period tested, while it did not show the greatest percentage increase over Turkey, it did have the highest test weight of all varieties under test at that time. In 1941, at the Fort Hays Agricultural Experiment Station, Red Chief had a test weight of 66 pounds per bushel compared with 65 pounds for Chiefkan, 61 pounds for Blackhull, and 60 pounds for Turkey. Early Blackhull, in certain seasons, may not have a high test weight but generally is equal to Blackhull.

TABLE 1.—*Test weight of Blackhull wheats in comparison with Turkey.**

Variety	Period tested	No. of tests	Av. test weight	Turkey in same tests	Per cent of Turkey
Blackhull	1919–43	290	58.4	56.7	103
Superhard	1926–31	18	61.0	58.2	105
Early Blackhull	1928–43	201	59.0	57.4	103
Clarkan	1931–43	115	57.9	55.2	105
Chiefkan	1935–43	229	59.1	55.7	106
Kanhull	1935–38	2	58.6	54.8	107
Red Chief	1941–43	89	61.3	58.3	105

*Data obtained by the Kansas Agricultural Experiment Station from nursery and plot tests at Manhattan, plot tests at Hays, and in cooperative experiments on farms in Kansas.

Clarkan is a soft wheat and the comparison given is with hard wheat grown in eastern Kansas. Other data not reported here show that Clarkan exceeds in test weight all other soft wheats now grown in the state. The plump berry and the high test weight of the Blackhull wheats are attractive to the farmer and often command a premium on the market.

YIELD

The increase in acreage and long-time popularity of Blackhull indicate that farmers found it a satisfactory wheat. Most farmers will choose the crop or variety that yields the highest net return and Blackhull generally has out-yielded Turkey. Higher yield and higher test weight of Blackhull compared to Turkey accounted for its widespread use in the period from 1917 to 1935, after which the acreage declined as better varieties became available. The data of Table 2, giving yield comparisons in experimental trials, show that all members of the group have outyielded Turkey except Kanhull.

TABLE 2.—*Yield of grain in bushels per acre of Blackhull wheats in comparison with Turkey.**

Variety	Period tested	No. of tests	Av. yield	Turkey in same tests	Per cent of Turkey
Blackhull	1919–43	517	22.1	21.0	105
Superhard	1926–31	18	33.7	30.4	111
Early Blackhull	1928–43	411	22.0	21.0	105
Clarkan	1931–43	121	26.0	22.5	116
Chiefkan	1935–43	250	24.2	20.4	119
Kanhull	1935–38	4	22.4	27.0	83
Red Chief	1941–43	109	26.7	25.0	107

*Data obtained by the Kansas Agricultural Experiment Station from nursery and plot tests at Manhattan, plot tests at Hays, and in cooperative experiments on farms in Kansas.

Kanhull and Chiefkan were released the same year and since Chiefkan outyielded Kanhull the latter was never grown very extensively. Superhard yields in Table 2 appear to be higher relative to Turkey than Blackhull; however, during the period Superhard was tested, Blackhull yielded 33.4 bushels per acre, or essentially the same as Superhard. Clarkan perhaps should be compared with a soft wheat or Kawvale since it is adapted only to the soft wheat area of Kansas. Kawvale, a semihard wheat, has a lower test weight than Clarkan but has produced greater yields and is more popular with farmers in the eastern part of the state.

KERNEL CHARACTERISTICS

The kernels of Blackhull wheats, except Clarkan, tend to be larger, plumper, and longer than those of Turkey and almost never show any yellowberry. Chiefkan, Red Chief, and Clarkan kernels usually are smooth even when other varieties in the same test may be shriveled. In adverse seasons it seems that these varieties develop kernels no larger than the plant can fill out and produce a plump berry. Occasionally the seedcoat splits longitudinally down the back as the endosperm enlarges inside what appears to be a covering of fixed size but too small. Generally the grain has a nice appearance and is attractive to both the farmer and buyer. Under certain conditions the varieties can be distinguished fairly readily by the kernel characters. Superhard was selected from Blackhull on the basis of its kernel characteristics, but ordinarily it cannot be distinguished from Blackhull unless both varieties are grown in adjacent fields or plots.

The important difference is the resistance to bleaching of the Superhard kernel when exposed to weathering, thus Superhard retains bright color longer than Blackhull. Likewise, Chiefkan and Red Chief are similar and on grain characters alone would be difficult to tell apart. They differ somewhat in their resistance to bleaching, Red Chief retaining its color longer than Chiefkan. A wavy or crooked crease is typical of kernels of Blackhull wheats, being least conspicuous, perhaps, in the Clarkan variety.

Red Chief and Chiefkan kernels have one prominent morphological character in common, i. e., a concave curved ridge along the back, referred to as "swayback". Kernels of most varieties have a straight or slightly arched ridge along the back when viewed from the side. In plump samples of Red Chief and Chiefkan 95% or more of the kernels generally show this character, but it is less distinct if the grain is shriveled. Data are available that indicate sway-back is inherited as a dominant character.

Where did Chiefkan and Red Chief obtain this character? Dines (10) made use of the sway-back character as a guide in his grain identification key for soft wheat and also for Chiefkan. A few typical sway-back kernels can be found in samples of Harvest Queen and Fultz. In the samples studied more of these were found in Harvest Queen than in Fultz. Mr. Clark has grown Harvest Queen on his farm and it is probable that Clarkan was derived from a Blackhull-Harvest Queen cross. Some hard beardless segregates may have become crossed with Superhard, resulting in Chiefkan. In other words, the sway-back character may have come from Harvest Queen. Mr. Clark has asserted that Red Chief is not related to Chiefkan, but since this character is common to both, one is led to believe they may have some ancestors in common. Fig. 1 shows the sway-back character on Chiefkan, Harvest Queen, and Red Chief. Blackhull, resembling Turkey, which does not show this character, is also shown.

Clarkan is classed as a soft wheat. The kernels are shorter and have a darker color than most soft wheats, and also are shorter than those of other Blackhull wheats. The grain usually can be distinguished from other Kansas wheats by these characteristics.

QUALITY CHARACTERISTICS

Milling and bread-making quality of Blackhull and the varieties belonging to this group have been discussed at length by a number of investigators (3, 14, 15, 17, 18, 19).

Shollenberger and Clark (18) appear to have given the first report on the milling quality of Blackhull. They reported that Blackhull "averaged slightly higher than Kharkof in test weight per bushel, but —slightly less in yield of flour". Parker (15) gave a 4-year summary of data on milling and baking as determined in the Department of Milling Industry, Kansas Agricultural Experiment Station, in which the higher test weight of Blackhull was not reflected in higher yields of flour as was expected. Similar results were reported by Salmon, *et al.* (17), by Bayfield and West (3), and others. Bates (2) in anatomical studies found that Blackhull and Chiefkan had a greater combined

thickness of the bran and aleurone layers than Turkey and concluded this would be an important factor in determining the percentage of flour extraction. All members of the Blackhull group have not been tested so widely as Blackhull, hence a final conclusion for the group is not possible at this time, but it appears that the high test weight leads to unwarranted expectation in flour yield. Even so, the flour yields of Chiefkan and Red Chief appear to be satisfactory.

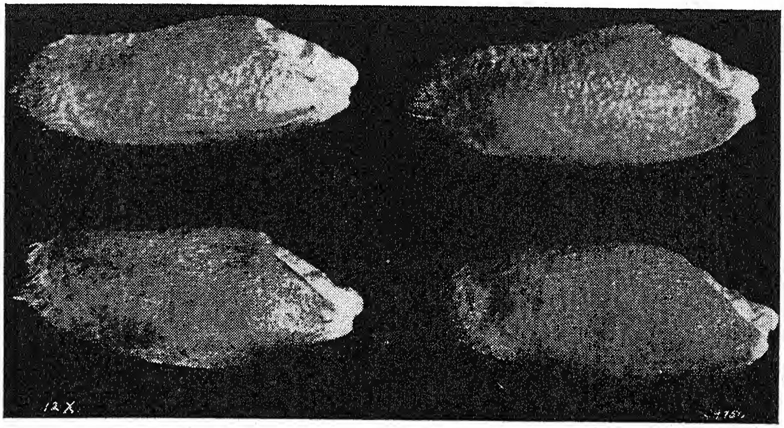


FIG. 1.—Illustration of kernel shape of Chiefkan, upper left; Red Chief, lower left; Harvest Queen, upper right; and Blackhull, lower right. Chiefkan and Red Chief commonly have about 95% of the kernels showing the depression (sway-back) on the back. Similar kernels also can be found in Harvest Queen. Blackhull does not show this characteristic.

Salmon, *et al.* (17) stated that "Blackhull produced as good loaves as did the other varieties", including Turkey when the doughs were mixed gently as by the hand methods, whereas "when the dough was mixed severely, Blackhull was considerably poorer than either Turkey or Kanred." Swanson and Kroeker (19) showed that the ranking of Tenmarq, Kanred, Blackhull, and Superhard for bread making purposes was in the order named when the mechanical modification method was used, but by the bromate method, the ranking was Blackhull, Superhard, Kanred, and Tenmarq. The Blackhull samples had low resistance to mechanical action but were greatly benefited by oxidizing agents such as potassium bromate.

Larmour, *et al.* (14) found it "improbable that Turkey, Blackhull, and Kanred are differentiated in respect to loaf volume at any point in their protein ranges". They found Chiefkan to possess distinctly inferior quality, noting that flour of Chiefkan at 14.6% protein gave the same sized loaves as standard varieties at 11.2% protein. Bayfield and West (3) confirmed these results and added that Early Blackhull also possessed inferior qualities in their tests.

Swanson and Kroeker (19) reported preference ratings from 17 cooperating cereal chemists on Tenmarq, Kanred, or Turkey, Blackhull, and Superhard for bread making purposes. Blackhull was ranked

first by three chemists and last by two; Superhard was rated first by one chemist and last by 11.

Dines (9) found in a cooperative test by nine milling and baking laboratories in Oklahoma and Kansas that Turkey was preferred, Blackhull was not particularly discriminated against, but Early Blackhull and Chiefkan were decidedly inferior. One sample of Superhard was included in tests reported by Dines and was strongly discriminated against by the two laboratories receiving it.

Bayfield and West (3) cited a report by Parker and Bayfield in which preference ratings were requested from 26 laboratories after each had an opportuinty to bake flour from Turkey, Blackhull, Tenmarq, and Chiefkan milled from wheat grown on adjacent acre plots. Chiefkan was ranked fourth by every laboratory, Turkey and Tenmarq were first or second choice in every case except in three laboratories where Blackhull was ranked first or equal to Turkey and Tenmarq. In respect to baking characteristics, Blackhull should be distinguished from the other varieties of the group.

The Blackhull wheats differ from Turkey and differ among themselves in general market quality factors. They have a thick bran and do not produce so high a yield of flour as their high test weight would indicate. Flour milled from Blackhull wheats has a low yellow pigment content. They have a short wheatmeal fermentation time, a characteristic of soft wheats (8). In handling-properties of the flour, some of these wheats tend to have a low water absorption, although Chiefkan and Red Chief have high water absorption. The Blackhull wheats produce a mellow or less elastic dough requiring a shorter mixing time and produce average or smaller size loaves of bread than Turkey. Blackhull and Early Blackhull generally have softer grain texture than Turkey, while Superhard, Chiefkan, and Red Chief are harder. Kanhull has not been tested for quality factors. Clarkan is accepted as a true soft wheat variety, although it is somewhat harder in texture than standard soft varieties and tends to produce a low yield of flour.

What can one conclude about the quality of the Blackhull wheats? Larmour (13) divides what the trade means by "quality" into three parts, namely, (a) fundamental quality or capacity of the flour with reference to a standard to fulfill the predictions made on the basis of its protein content as affected by the germ plasm of the wheat plant and the environment under which it is grown; (b) specific adaptability or suitability of wheat for a certain method of milling or particular baking technic; and (c) preference of individuals for certain classes, grades, or varieties.

In discussions of wheat quality, these three concepts of quality are often confused with one another and with a fourth, the nutritional value when eaten by animals or man. Hence, in any evaluation of wheat quality, the criteria being used should be stated fully. Much of the reaction to Blackhull in trade channels reflects adaptability and preference; nevertheless, such reaction reflects great economic pressure. Little or no evidence is available to show that wheat varieties grown under the same environment and having the same total amount of protein differ in nutritional value or palatability.

Data cited above show that Blackhull and Turkey produce nearly equal loaf volumes when each is subjected to the methods best suited to it. On this same basis Chiefkan, Red Chief, Superhard, and Early Blackhull are not equal to Blackhull. It must be admitted that other baking methods may modify this conclusion even though many cereal chemists have tried all of the usual modifications in making baking tests with these wheats. The Blackhull wheats differ from Turkey in dough-handling properties and bakeshop performance and therefore introduce a greater variability than may be desirable in winter wheat grown in Kansas and adjacent territory.

OTHER CHARACTERISTICS

All of the Blackhull wheats have a stiffer straw than Turkey with the probable exception of Kanhull and Early Blackhull. Red Chief has the stiffest straw of the group. In certain seasons, especially during periods of wet weather, Blackhull, Early Blackhull, and Chiefkan have been observed to break over. This lodging may be due to glume-blotch or other wet-weather diseases to which certain of the Blackhull wheats are very susceptible but which may attack other varieties also. Early Blackhull does not have a stiff straw and often lodges before it is harvested.

Fields of Blackhull wheats often can be identified early in the growing season by the vigorous and erect growth habit of the leaves.

The Blackhull wheats are not equal to Turkey in winterhardiness. Early Blackhull is the least winterhardy of the group. While this fact is well substantiated by experimental data, varietal differences have accounted for only a minor portion of the losses from winter killing in the southern Great Plains where Blackhull wheats have been grown.

All of the Blackhull wheats are susceptible to loose smut (1), and are susceptible to bunt, especially Chiefkan and Red Chief (12, 16, 20). They vary in their reaction to leaf rust, Blackhull and Chiefkan exhibiting some tolerance to this disease as well as to stem rust (20). The Blackhull wheats also show some tolerance to hessian fly (20).

The leaves of these varieties show a yellow or chlorotic stippling under certain conditions. Blackhull and Clarkan show this character only slightly, while Chiefkan and Red Chief show it to a rather striking degree. The stippling becomes prominent about heading time. Sometimes the leaves of Chiefkan turn nearly yellow as the areas enlarge and coalesce. The other varieties also show some degree of yellowing. No disease-causing organism has been found associated with these spots, but a genetical basis is indicated. Chiefkan was crossed with Hard Federation-Kawvale and the stippling appears to be inherited as a simple recessive[5].

Blackhull, Chiefkan, Clarkan, and Red Chief have been reported (11) as carrying a dominant factor *Le2* which, in combination with *Le1* from other wheats, produces a lethal F_1 plant. Kanhull, Super-

[5]Unpublished data. C. O. Johnston, Bureau Plant Industry, Soils, and Agricultural Engineering, Agricultural Research Administration, U. S. Dept. of Agriculture, Manhattan, Kans.

hard, and Early Blackhull also have been found to carry the factor *Le2*. Fig. 2 shows the complementary action of these genes. Chiefkan is the parent carrying the factor *Le2* and Marquillo-Oro carries the factor *Le1*. The F_1 plant shown is nearly dead. The factor *Le2* appears to be much more common in soft wheats (11) than in hard wheats. The Blackhull wheats so far as are known are the only hard wheats that carry this factor. It is of interest to note that all in the group carry this factor, which may indicate that very little or no additional germplasm has been added since the original Blackhull-beardless soft wheat natural hybrid occurred in 1916 or that this factor is closely associated with one or more of the Blackhull traits.

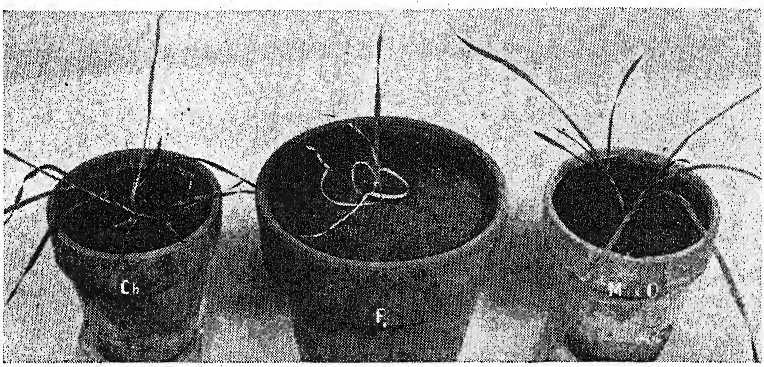


FIG. 2.—Complementary lethal action of genes *Lel* and *Le2*. Chiefkan (Ch) carries the factor *Le2*. A selection from Marquillo×Oro (M×O) carries the factor *Le1*, this factor being transferred to the selection from Marquillo. When Chiefkan and the selection from Marquillo×Oro carrying the factor *Le1* were crossed, the F_1 hybrid plants (F_1) died in the early stages of growth. *Le2* is a factor commonly found in soft wheats and all of the Blackhull wheats.

DISCUSSION

Introductions of Turkey wheat are known to have contained both red and black-chaffed types. A number of red-chaffed types have been selected from Turkey by farmers, but none of them has shown promise. Blackhull and its derivatives are the only types selected from Turkey by farmers to gain such wide popularity in the hard winter wheat area. Blackhull is unique in having higher test weight than any other variety selected from the original Turkey. Nothing has been said concerning the origin of Blackhull except that it resulted from the increase of three black heads found in Turkey wheat. The softer texture, appearance of the kernel, the short fermentation time with the dough-ball test, some tolerance to hessian fly, erect leaves, and the presence of the factor *Le2* are indications that Blackhull is related to soft wheats.

Salmon, *et al.* (17) have stated that Blackhull resembled soft wheats in many respects. Although Blackhull has some of the characteristics of soft wheats it is considered to be a hard red winter wheat and is marketed as such. Soft wheats generally are not thought of as having

especially high test weight. Recombination and complementary behavior of factors for high test weight could have occurred when Turkey was crossed with a soft wheat either before the wheat was imported to this country or very soon after it was grown in Kansas. Since Harvest Queen was the most common soft wheat grown in south-central Kansas, it is the most likely soft wheat parent, if the cross with Turkey occurred in this country. Harvest Queen carries the factor *Le2*. The fact that selections have been made only in Blackhull and crosses of Blackhull × beardless soft wheat (probably Harvest Queen) would account for all members of the group carrying the *Le2* factor.

SUMMARY

Blackhull, Superhard, Clarkan, Kanhull, Chiefkan, and Red Chief winter wheats were developed by Earl G. Clark, a farmer wheat breeder living near Sedgwick, Kans. Early Blackhull was selected by A. P. Haeberle, a farmer living near Clearwater, Kans. These are designated "Blackhull wheats" in this discussion.

All of these varieties have high test weight, good yield, and attractive appearance.

The varieties differ in kernel characters. Blackhull is softer than Turkey, Superhard is similar in size and shape to Blackhull, but is harder in texture and does not bleach readily in the field. Red Chief and Chiefkan have the sway-back character sometimes found in Harvest Queen and other soft wheats. Red Chief, like Superhard, is resistant to weather-bleaching in the field. Clarkan is a soft wheat with a short, plump, fairly dark-colored berry. Grain from the varieties with hard texture almost never show any yellowberry.

Blackhull wheats have a rather short wheat meal fermentation time, thick bran, flour yield not as high as the test weight would indicate, and a short dough-mixing time. Blackhull has been accepted by the trade as a hard wheat and Clarkan as a soft wheat. Apparently Chiefkan, Red Chief, Superhard, and Early Blackhull are not equal to Blackhull in baking characteristics.

The Blackhull wheats are not so winterhardy as Turkey. All the members of this group are susceptible to loose smut and bunt but have some tolerance to hessian fly. Blackhull and Chiefkan have some tolerance to leaf and stem rust.

These wheats have a characteristic yellowing or chlorotic stippling of the leaves that is variable in expression from season to season and in one cross was inherited as a simple recessive factor.

A lethal complementary factor *Le2*, commonly found in soft but not in hard varieties, is carried by the Blackhull wheats.

LITERATURE CITED

1. ATKINS, I. M. Reaction of some varieties and strains of winter wheat to artificial inoculation of loose smut. Jour. Amer. Soc. Agron., 35:197–204. 1943.
2. BATES, JAMES C. Varietal differences in anatomy of cross-section of wheat grain. Bot. Gaz., 104:490–493. 1943.
3. BAYFIELD, E. G., and WEST, GLENN A. Baking tests and the evaluation of new wheats. Cereal Chem., 19:493–507. 1942.

4. CALL, L. E., and PARKER, JOHN H. Blackhull wheat. Biennial Rpt. Kans. State Board Agr., 23:184–192. 1923.
5. CLARK, J. ALLEN, and BAYLES, B. B. Classification of wheat varieties grown in the United States. U. S. D. A. Tech. Bul. 459. 1935.
6. ——————, ——————. Classification of wheat varieties grown in the United States in 1939. U. S. D. A. Tech. Bul. 795. 1942.
7. ——————, and QUISENBERRY, K. S. Distribution of the varieties and classes of wheat in the United States in 1939. U. S. D. A. Circ. 634. 1942.
8. CUTLER, G. H., and WORZELLA, W. W. A modification of the Saunder's test for measuring "quality" of wheats for different purposes. Jour. Amer. Soc. Agron., 23:1000–1009. 1931.
9. DINES, F. T. Quality of wheat varieties grown in Oklahoma in 1938. Okla. Agr. Exp. Sta. Circ. 85. 1939.
10. ——————. General kernel characteristics of commercially important hard red winter wheat varieties grown in the Southwest. Texas Wheat Improvement Assoc., Amarillo, Texas. 1940.
11. HEYNE, E. G., WIEBE, G. A., and PAINTER, R. H. Complementary genes in wheat causing death of F_1 plants. Jour. Hered., 34:243–245. 1943.
12. JOHNSTON, C. O., and QUISENBERRY, K. S. Summary of the Great Plains uniform winter wheat bunt nursery, 1942. U. S. D. A., Bur. Plant Indus., Div. Cereal Crops and Dis. (Unnumb. Pub.), December, 1942. (Mimeographed.)
13. LARMOUR, R. K. A comparison of hard red winter and hard red spring wheats. Kans. Agr. Exp. Sta. Bul. 289. 1940.
14. ——————, WORKING, E. B., and OFELT, C. W. Quality tests on hard red winter wheats. Cereal Chem., 16:733–752. 1939.
15. PARKER, JOHN H. Wheat improvement in Kansas, 1874–1934. Biennial Rpt. Kans. State Board Agr., 34:139–164. 1935.
16. QUISENBERRY, K. S. Comparison of winter-wheat varieties grown in cooperative plot and nursery experiments in the hard red winter wheat region. U.S.D.A., Bur. Plant Indus., Div. Cereal Crops and Dis. (Unnumb. Pub.) January, 1936. (Mimeographed.)
17. SALMON, S. C., SWANSON, C. O., LAUDE, H. H. Blackhull wheat in Kansas. Kans. Agr. Exp. Sta. Bul. 241. 1927.
18. SHOLLENBERGER, J. H., and CLARK, J. ALLEN. Milling and Baking experiments with American wheat varieties. U.S.D.A. Bul. 1183. 1924.
19. SWANSON, C. O., and KROEKER, E. H. Testing wheat varieties for milling and baking quality. Cereal Chem., 9:10–33. 1932.
20. U. S. DEPT. OF AGRICULTURE. Reaction of wheat varieties to the major diseases and hessian fly. U. S. D. A., Bur. Plant Indus., Bur. Entom. and Plant Quar., and State Agr. Expt. Stas. (Unnumb. Pub.) 1941. (Mimeographed.)

REDUCTION IN YIELD OF WINTER WHEAT DUE TO REMOVAL OF HEADS AT HEADING TIME[1]

Hubert M. Brown[2]

To many who have observed the black masses of loose smut, *Ustilago tritici*, spores as they appear in a field of wheat at heading time, there doubtless has come the question, Will the reduction in yield due to the destruction of wheat heads by the smut be proportional to their percentage occurrence or will the remaining undestroyed heads be able to compensate in part for the destruction?

In the literature on loose smut no data were found dealing with the quantitative determination of the reduction in yield of grain due to this disease. The practical difficulties of obtaining sufficient seed with appreciable amounts of loose smut and of being certain that the loose smut infected seedings would not be killed out during the winter, prompted an attempt to simulate the removal of wheat heads from production due to their destruction by loose smut. This simulation consisted of removing certain heads by cutting them from the culm shortly after heading had occurred. The experiment was begun in the fall of 1937 and continued through the crop of 1941. The data for the 4 years are presented here.

MATERIALS AND METHODS

The plan of the experiment involved the removal of certain wheat heads at heading time and the subsequent determination of the yields of grain. The layout for the 1938 crop included American Banner and Baldrock winter wheats. Each variety was planted in a set of four randomized blocks with 13 plots per block. No treatment was given one plot. The treatments given to the other 12 involved the removal of the heads in three rates, leaving 95%, 90%, and 80% of the heads; in two arrangements, heads cut singly or cut in bunches of five; and at two heights, cut high, between the head and the top leaf, or cut low, within 3 inches of the ground. (See Table 1.) The plots were three rows wide, with 1 foot between rows, and were cut to 16 feet long shortly before harvest. All the plots of a variety were planted with the same drill. All rows of a plot were given the same treatment. No record was made of the numbers of heads removed nor of those that matured.

During the next 3 years, 1939–41, a third variety, easily identified at heading time, was used to represent the varying percentage of loose smut. As American Banner and Baldrock are awnless, a bearded type, Red Rock, was chosen. The six mixture ratios of awnless (American Banner) to bearded (Red Rock) which were used were: 100:0, 95:5, 90:10, 85:15, 80:20, and 75:25%. These mixtures, hereafter designated by the percentage awnless, were randomized as in a Latin square. A second Latin square, using Baldrock instead of American Banner, was also planted. All plots were four rows wide, with 12 inches between rows, and were cut to 16 feet long shortly before harvest. As the varieties did not have the same kernel size, they were carefully screened and the proper amounts mixed together to give the desired mixture ratios by count. All plots of a square were planted with the same drill. At heading time, the bearded heads were removed by cutting them off just below the head and the number for each row recorded. Later, counts were made of the numbers of awnless heads. All six

[1]Part of these data were presented in a paper at the annual meeting of the Society held in Washington, D. C., in December 1941. Contribution from the Farm Crops Section, Michigan Agricultural Experiment Station, East Lansing, Mich. Journal Article No. 597 new series. Received for publication June 2, 1944.

[2]Assistant Professor and Research Assistant in Farm Crops.

replications were thus counted in 1939 and 1940, but only two replications were counted in 1941.

Each row of every replication, each of the 4 years, was cut, bagged, threshed, and weighed separately.

RESULTS

1938 CROP

The treatment mean yields of grain for the 1938 crop were converted into relative yields of the 100% uncut (no-treatment) means. The differences (R-U) between the relative yields (R) and the percentages of uncut heads (U) are given in Table 1. A positive difference in the table indicates that the reduction in relative yield due to head removal was not as great as the reduction in percentage of uncut heads. The data were grouped according to variety and to each of the three methods of treatment. The group means are given and their significance may be judged by the accompanying analysis of variance.

The varietal averages, 1.3% for American Banner and 4.7% for Baldrock, indicate that the varietal responses were not equal though in the same direction. Height of cutting tended to show nearly as great a difference between means as did variety; the mean low cutting being 1.6%, while that for high cutting was 4.3%. When the data were assembled to whether the heads were removed singly or in bunches of five, the means were 2.0% and 4.0%, respectively. The rate means, though they showed no significant differences among themselves, were all positive.

TABLE 1.—*Differences (R-U) between relative yield percentages (R) and percentage of uncut heads (U), 1938 data.*†

Cutting treatment		American Banner			Baldrock		
Height	Arrangement	95% uncut	90% uncut	80% uncut	95% uncut	90% uncut	80% uncut
High	Singly	0.7	2.6	6.5	1.9	5.5	8.3
	Bunched	2.5	4.4	2.5	4.4	3.6	9.4
Low	Singly	-1.3	-1.2	-1.1	1.9	0.8	-0.3
	Bunched	0.2	1.6	-1.3	10.6	3.6	6.4

Means: Variety: American Banner 1.3%, Baldrock 4.7%.
Height: Low 1.6%, high 4.3%.
Arrangement: Singly 2.0%, bunched 4.0%.
Rate, per cent uncut: 95%, 2.6%; 90%, 2.6%; 80%, 3.8%

Analysis of variance			
Source	Df	Variance	F
Varieties	1	66.6782	45.8**
Height	1	43.7315	30.0**
Arrangement	1	13.1982	9.1*
Rate	2	3.7562	2.6
V×H	1	6.1902	4.2
V×A	1	20.9235	14.4**
V×R	2	4.9072	3.4
H×A	1	28.3835	19.5**
H×R	2	19.4030	13.3**
A×R	2	9.2422	6.3*
Remainder	9	1.4564	—
SD=1.21%	-	—	—

*Significant.
**Highly significant.
†The average yields in bushels per acre for the 100% uncut plots were for American Banner 39.4 bus. and for Baldrock 35.9 bus.

1939–1941 CROPS

As has been mentioned, the plan of the experiment for the three crops of 1939–41 was changed to include varying percentages of a bearded wheat mixed into each of two awnless varieties. The bearded heads were counted as they were removed at heading time and the

TABLE 2.—*Differences (C–P) between percentages of awnless heads counted (C) and percentages of awnless grain planted (P), 1939–41 data.*

Variety	Yr.	Percentage of awnless planted						Analysis of variance			
		100	95	90	85	80	75	Source	Df	Variance	F
American Banner	1939	-0.7	0.0	0.9	2.5	2.3	4.5	Varieties	1	63.2025	13.9**
	1940	-0.2	0.3	-0.3	-0.1	0.9	-0.6	Years	2	11.7978	2.6
	1941	-0.5	-1.5	-2.9	-2.4	-2.6	-5.4	V×Y	2	25.1633	5.5*
								Mixtures	5	7.8869	1.7
	Av.	-0.5	-0.4	-0.8	0.1	0.2	-0.5	V×M	5	11.5505	2.5
								Y×M	10	2.2328	—
Baldrock	1939	-0.1	-1.6	-3.6	-6.7	-6.2	-7.6	V×Y×M	10	4.5464	—
	1940	-0.1	-0.5	-1.3	-1.1	-4.8	-2.5	(error)			
	1941	-0.1	-0.2	-1.5	-2.9	-10.5	-2.6				
	Av.	-0.1	-0.8	-2.1	-3.6	-7.1	-4.2				
Av. both varieties		-0.3	-0.6	-1.4	-1.8	-3.5	-2.4	S.D. = 2.13%			

*Significant.
**Highly significant.

TABLE 3.—*Differences (R-P) between relative yield percentages (R) and percentages of awnless grain planted (P), 1939–41 data.*†

Variety	Year	Percentage of awnless planted					Anlaysis of variance			
		95	90	85	80	75	Source	Df	Variance	F
American Banner	1939	0.5	0.9	0.2	1.8	4.2	Varieties	1	29.0833	1.8
	1940	2.7	2.9	3.1	4.1	5.1	Years	2	154.1455	9.3**
	1941	0.9	-13.2	-1.9	-6.5	-13.9	V×Y	2	53.7760	3.2
							Mixtures	4	14.4954	—
	Av.	1.4	-3.1	0.5	-0.2	-1.5	V×M	4	8.7346	—
							Y×M	8	11.8427	—
Baldrock	1939	2.8	-1.1	3.4	-2.1	2.3	V×Y×M	8	16.6139	—
	1940	2.2	-5.5	-6.7	-9.1	1.1	(error)			
	1941	-5.6	-5.0	-7.3	-3.6	-4.6				
	Av.	-0.2	-3.9	-3.5	-4.9	-0.4				
Av. both varieties		0.6	-3.5	-1.5	-2.5	-1.0	S.D. = 4.08%			

**Highly significant.
†The average yields in bushels per acre for the 100% awnless plots were:

Year	1939, bu.	1940, bu.	1941, bu.	Av., bu.
American Banner	34.7	25.8	35.1	31.9
Baldrock	30.9	24.9	35.7	30.5

awnless heads were counted sometime before cutting. The average percentages of awnless heads were then obtained for each mixture rate. The differences (C–P) between these average percentages of awnless heads (C) and the percentages of awnless grain planted (P) give some indication as to how closely the planted ratios were approximated. The data are presented in Table 2. In general, less awnless heads were produced than might have been expected on the basis of the planted ratios even when allowing for the bearded types in the awnless varieties. This condition was especially true of Baldrock at the lower percentages.

The yields of grains were converted into relative yields, using the 100% awnless plots as standard. The differences (R–P) between these relative yields (R) and the percentages of awnless grain planted (P) are given in Table 3. In general, a decrease in the number of mature heads caused a slightly greater than proportional drop in yield.

CONCLUSION

The destruction of heads of winter wheat by loose smut was simulated by removing certain percentages of heads at heading time. Four rates of removal were used in 1938 and six in 1939–41.

The data for the 4 years indicate that the percentage reduction in yield due to removal of heads at heading time was approximately the same as the percentage reduction in number of heads. The closeness of approximation was influenced by seasonal and varietal differences.

Insofar as the manner of conducting this test simulated losses in winter wheat due to loose smut, it can be considered that such losses in yield are approximately as great as the percentage of loose smut.

NOTE

EFFECTS OF PROCESSING ON GERMINATIVE CAPACITY OF SEED OF TALL OATGRASS, *ARRHENATHERUM ELATIUS* (L.) MERT. AND KOCH

ONE of the reasons some very promising grasses are not in common use is the presence of awns or other appendages which make seeding through a drill difficult. An efficient system of processing[1] seed to remove appendages and thus facilitate seeding has been reported.[2] By the expedient of hammering at controlled rates of speed and feeding, and by using the correct screen, it was found possible to obtain the required results with a miminum of injury to the seed. Such hammering and subsequent cleaning has become an accepted practice for processing many kinds of seed.

Although seed processing has recognized advantages, there remains the possibility of an adverse effect on the germinative capacity of the seed. This effect could be evident either immediately or after warehouse storage. In some quarters there is reluctance to plant processed seed carried over for a single season. The species around which most controversy has centered is tall oatgrass. This article reports the results from numerous tests with processed and stored tall oatgrass seed.

Lots of tall oatgrass seed have been processed by the Pullman Nursery each year, beginning in 1939. Aliquot samples of one lot were taken for determinations of degree of de-awning and dehulling, injury to the caryopses, purity, and germination. The samples were stored in a dry, unheated room and tested for germination in subsequent years. The laboratory tests were made by Dwight D. Forsyth, Washington State College Seed Analyst. Germination tests were based on duplicate samples of 100 seeds each, according to standard technics. The percentage of seed injured was determined by examination under a 20 × binocular microscope.

The degree of treatment required to facilitate planting depends upon the nature of the planting and the species used. Tall oatgrass is usually milled twice. After the first run the awned fraction is removed by a scalper, remilled, and then both fractions recombined. Table 1

TABLE 1.—*Condition of tall oatgrass seed aliquots as affected by number of times milled.*

Fraction	Natural %	De-awned %	Dehulled %	Injured %
Unmilled check	90.75	8.00	—	1.25
Milled once	45.00	20.00	34.00	1.00
Milled twice (recommended)	14.00	36.00	47.25	2.75
100% dehulled	—	—	—	3.00

[1]The term "processing", as here used, includes both middling (hammering) and cleaning.

[2]SCHWENDIMAN, JOHN L., SACKMAN, ROLAND F., and HAFENRICHTER, A. L. Processing seed of grasses and other plants to remove awns and appendages. U.S.D.A. Circ. 558. 1940.

shows the condition of four aliquots of tall oatgrass seed following different degrees of processing. The check lot was subject only to the normal threshing and cleaning operations. The completely dehulled lot was removed from a separate fraction of processed seed.

The check indicates that there is some de-awning and injury in normal threshing and cleaning. The extent of dehulling and further de-awning during milling is in proportion to the number of times the seed is milled. The percentage of injured seed is not seriously increased by any of the treatments.

The effect of these treatments on germination of the different aliquots is shown in Table 2.

TABLE 2.—*The retention of viability in processed seed of tall oatgrass as influenced by degree of milling, 1938 crop, de-awned in January 1939.*

Date of test	Months after processing	Duration of germination test in days	Germination, %			
			Unmilled check	Milled once	Milled twice	Seed 100% dehulled
Jan. 1939......	—	13	88.0	—	90.0	—
Mar. 25, 1940..	14	7	96.0	90.5	92.0	79.5
Mar. 26, 1941..	26	13	94.5	85.0	87.0	75.0
Jan. 23, 1943..	48	25	92.5	89.0	74.5	74.0
Dec. 13, 1943..	59	16	88.5	85.5	74.5	67.0

The data show that the practice of milling twice causes no abnormal decrease in germination percentage for at least 26 months. This time interval allows for safe storage of the milled seed until the second planting season following the year of production.

There is a marked decline in germination of twice-milled seed between 26 and 48 months. This occurs despite the only slightly higher percentage of injured naked caryopses. The decrease in viability may have been caused by injury to caryopses of unhulled seed or by abrasion of the hulls, both points being difficult to ascertain by ocular inspection. Further study is desirable.

The completely hulled aliquot suffered a considerably greater loss in viability during the first 14 months than did the other lots of seed. Whether this is due to internal injury or to loss of hulls was not determined. Results from other tests with seed completely dehulled a few weeks prior to planting show no significant differences in germination or emergence when compared to performance of natural seed. Although the exact time element is not known, it appears evident that lots of 100% dehulled seed should not be prepared until shortly before time of planting.

The rumored immediate and rapid decline in germination of processed tall oatgrass seed is not substantiated by these results. With proper care, seed twice milled immediately after harvest can be safely stored until the second planting season following production.—JOHN L. SCHWENDIMAN and LOWELL A. MULLEN, *Nursery Division,*

Soil Conservation Service, cooperating with the Washington Agricultural Experiment Station and the Division of Forage Crops and Diseases, Bureau of Plant Industry, Soils and Agricultural Engineering, Pullman, Washington.

BOOK REVIEWS

CONSERVATION IN THE UNITED STATES

By A. F. Gustafson, C. H. Guise, W. J. Hamilton, Jr., and H. Ries. Ithaca, N. Y.: Comstock Publishing Co. Ed. 2. XI + 477 pages, illus. 1944. $4.

CONSERVATION IN THE UNITED STATES, in its original form, has fully met its authors' purpose "in providing the basic facts essential to an understanding of current problems and aid in the promotion of true conservation." To keep this commendable text in accord with new developments, this second edition has been prepared with the inclusion of the most recent available statistics, additional supplementary readings, and some changes in nomenclature organization and subject matter.

The introduction has been enlarged and materially improved in its content. In Part I, Conservation of Soil and Water Resources, among the new items added, is a timely discussion of soil conservation districts. Part II, Conservation of Forests, Parks, and Grazing Lands, is based on the general outline of the first edition, but in content it is practically a complete rewriting. The existing presentation is more logically arranged and complete than that offered in the original edition. In Part III, Conservation of Wildlife, and Part IV, Conservation of Mineral Resources, the standard set in the first writing has been retained in the second edition, essentially with the introduction of the latest available statistics and with emphasis on resources in relation to the war. Some new illustrations have been added and the mechanics of the original pictures and graphs have been sharpened and clarified, thus, greatly enhancing the usefulness of the text. In all, the authors have made a real contribution to the limited number of worthy publications in the field of conservation.—F. A. CARLSON.

THE FIELD SEED INDUSTRY IN THE UNITED STATES

By Frank Victor Beck. Madison: Univ. of Wisconsin Press. XXII + 230 pages, illus. 1944. $3.

THIS timely contribution presents the results of a 5-year study of important grass and legume seeds with particular reference to the economy of their production and distributions. The study was undertaken through a fellowship supported at the University of Wisconsin at first by certain wholesale distributors of seeds and later by the Field Seed Institute of North America. Although not indicated in the title, the book is concerned almost wholly with seeds of hay and

pasture plants commonly grown in the northern half of the United States.

The author first sketches briefly the development of the grass seed industry in the United States since Colonial days, and then treats more fully the topics of economics of production, distribution and consumption; seasonal and geographic patterns of seed sales; prices and price trends: prices of seed in relation to other farm prices; factors affecting seed prices; and commercial movement of seed crops. The text is supplemented by 19 tables and 49 maps and charts. An appendix is included containing 38 additional tables of basic data. The extended table of contents, lists of tables and figures, references, and index all help to make the book usable.

The volume is of primary interest to members of the seed trade but contains much information of value to agronomists, particularly information concerned with the economics of seed distribution. The book will also be useful to the agricultural economist.

For the most part the tables, figures, and text are clear. Some readers may wish the author would have chosen to express certain correlations as coefficients rather than as graphs. The author has brought together and interpreted a considerable body of data bearing on the economy of seed production in the United States.—R. J. GARBER.

AGRONOMIC AFFAIRS

ANNUAL MEETINGS CANCELLED

THE EXECUTIVE COMMITTEES of the American Society of Agronomy and the Soil Science Society of America have cancelled the 1944 annual meetings of the two organizations. The action followed upon extensive correspondence among the members of the two committees and a conference of a number of the officers of the two societies who were in Washington recently on other matters. An urgent request from the Office of Defense Transportation for cancellation of meetings of nationwide organizations and drastic restrictions placed on travel to scientific meetings of employees of the U. S. Dept. of Agriculture were determining factors in the decision to cancel the 1944 meetings.

Questions as to how the two societies should proceed for the coming year with respect to the election of officers and, in the case of the Soil Science Society, with regard to the publication of the PROCEEDINGS, as well as other matters, are now before the Executive Committees for consideration. Tentative plans call for completion of the program for the annual meetings with the publication of abstracts in the December issue of the JOURNAL. That issue would also carry complete reports of committees and officers. Announcements of the decisions of the Executive Committees regarding these and related matters will be forthcoming in the near future.

The annual meetings of the National Joint Committee on Fertilizer Application and the National Joint Committee on Nitrogen Utilization that are normally held preceding the meetings of the American

Society of Agronomy and Soil Science Society have also been cancelled.

NEWS ITEMS

The National Fertilizer Association has issued a catalog of kodachrome slides showing nutrient deficiency symptoms in a wide variety of plants. The collection has been made in cooperation with agronomists, horticulturists, and plant physiologists. Duplicates of the original slides may be ordered by any agricultural worker or teacher or any other interested person. A copy of the catalog may be obtained upon request to the Association, 616 Investment Building, Washington 5, D. C.

—A—

Professor Howard C. Rather, formerly head of the Farm Crops Department at Michigan State College, East Lansing, Mich., has been appointed Dean of a newly authorized Basic College in which all Michigan State College students are to be enrolled during their first two years. Roy E. Decker, recently assistant Extension Director and before that Extension Agronomist, has been appointed head of the Farm Crops Department. C. R. Megee, another long-standing member of the Farm Crops Department, has been named Assistant Dean of Agriculture and is in charge of agricultural instruction.

—A—

Professor Clyde H. Myers, who retired recently from the Department of Plant Breeding at Cornell University, died on August 5, following a long illness. Professor Myers, active in the affairs of the American Society of Agronomy for many years, served as special representative of the International Board of the University of Nanking, China, from 1926 to 1931.

—A—

On July 1, 1944, Professor James A. Bizzell, Professor of Soil Technology in the Department of Agronomy at Cornell University, having reached the age of 68, was retired with the title of Professor Emeritus. Professor Bizzell has been a member of the Cornell faculty since 1903 and is known at home and abroad for his research publications on many different soil problems. His investigations on the loss of plant nutrients in soil drainage as measured with lysimeters, on the influence of plants on nitrate accumulation in soils and upon succeeding crops, and on nitrogen mobility and economy in soils indicate the wide scope of his activities. Professor Bizzell is a Fellow of the American Society of Agronomy and many of his research papers have appeared in this Journal and in the Proceedings of the Soil Science Society of America. He will continue to reside in Ithaca, N. Y.

—A—

Professor D. B. Johnstone-Wallace, Agrostologist in the Department of Agronomy at Cornell University, returned to the United States on August 1 after a year and a half leave of absence granted

for war work in Great Britain. While abroad he served as Deputy Director and Head of the Agricultural Department of the National Institute of Agricultural Engineering at Askham Bryan near York, England. Here, Professor Johnstone-Wallace devoted special attention to machinery used for the preparation of grass silage and for the seeding of grasslands. In addition he made an extensive lecture tour through England, Scotland, and Wales, and spent some time at the plant breeding stations at Aberystwyth and Corstorphine as well as at the Ministry of Agriculture's Grassland Improvement Station at Dodwell near Stratford-on-Avon.

—A—

ACCORDING TO THE *New York Times*, a former Russian peasant named Shekhurdin has been awarded the title of Doctor of Agricultural Science by the Soviet government in recognition of his work in producing 24 new varieties of summer wheat, including a strain highly resistant to drought. Doctor Shekhurdin is said to have begun his work thirty-three years ago upon graduation from a primary agricultural school.

—A—

MEMBERS OF THE DEPARTMENT OF AGRONOMY of Colorado State College now in the armed services include Doctor B. Rodney Bertramson, who is a Captain in Military Government and when last heard from was in England; Doctor Ralph M. Weihing, an artillery officer in Texas; Captain Warren H. Leonard, with the Military Government, at present in Chicago; Lt. Robert S. Whitney, at present an air meteorological officer somewhere in France; and Professor Robert F. Eslick, with the Army Hospital Service. Mr. J. J. French has been added to the agronomy staff in connection with a slightly expanded corn improvement program.

—A—

THE NATIONAL FERTILIZER ASSOCIATION has just issued a well illustrated pamphlet entitled "Fertilizer Industry Forges Ahead". The story of the progress and service to farmers in the manufacture and distribution of fertilizers is told largely by means of charts, maps, and photographs. Copies of the pamphlet may be obtained upon request from the Association, 616 Investment Building, Washington 5, D. C.

—A—

DOCTOR GARTH W. VOLK, soil chemist at the Alabama Agricultural Experiment Station, has accepted a position as Soil Chemist at the Ohio Agricultural Experiment Station, Wooster, Ohio. Doctor Volk received the Ph.D. degree at the University of Wisconsin in 1935, and has had a wide experience in the field of soils and agronomic research. His experience covers periods of employment by the Research Department of the United Fruit Company, Oklahoma Agricultural Experiment Station, and the Alabama Agricultural Experiment Station.

DOCTOR H. R. ALBRECHT, Plant Breeder at the Alabama Agricultural Experiment Station, has accepted the position as Associate Plant Breeder at Purdue University, Lafayette, Ind. Doctor Albrecht received the Ph.D. degree at the University of Wisconsin in 1936 and since that date has done outstanding work in the field of plant breeding in Alabama.

—A—

THE AMERICAN LIBRARY ASSOCIATION announces that in furtherance of its aid to libraries in war areas the sum of $160,873.62 had been expended up to the end of 1943 for subscriptions to 325 scholarly and scientific journals, to be stored in this country for distribution after the war to libraries in war areas. The funds are provided by a grant from the Rockefeller Foundation, which has allotted from $50,000 to $70,000 annually for this purpose since 1941. The fund is administered by a Committee on Aid to Libraries in War Areas of the American Library Association. Thirty-five copies of each issue of this JOURNAL have been set aside for the past three years under the provisions of this project of the American Library Association.

—A—

THROUGH THE COURTESY of the British Central Scientific Office, Washington, D. C., we have received Volume I, No. 1, of *The Chinese Journal of Scientific Agriculture* published in September 1943. The *Journal* is to be published quarterly by the Ministray of Agriculture and Forestry at Chungking, China. The first number contains the following articles either in English or with English abstracts: Studies on the Inheritance of Dwarfness in Common Wheat, by W. K. Pao, *et al.* (published also in this JOURNAL in May 1944); Experiments on the Control of Cotton Diseases: I. Spraying with Bordeaux Mixture, by Lee Ling and Juhwa Y. Yarg; On the Inheritance of Pentoploid Wheat Hybrids, a Critique, by W. K. Pao and H. W. Li; The Phosphorus and Potash Requirements of Kiating Soils as Determined by Azotobacter Plaque Method, by H. Zanyin Gaw; Experiments on the Extraction of Nicotine from Tobacco Leaves and the Preparation of Nicotine Sulphate, by T. L. Chow and Lee Ling; The Orange Maggot in Kiangtsing (Szechwan), by Chen Fong-Ge and Wang Fei-Peng; Some Experiments on the Efficacy of Roy-kung-teng, *Tripterygium wilferdii* Hook, for the Treatment of Tapeworm and Roundworm in Chickens, by C. S. Lo and T. Y. Worg; Natural Crossing in *Vicia faba*, by Hsingnai Hua; and Cytology of Wheat and Its Application, by T. C. Chin.

—A—

AFTER many disappointing delays, due primarily to labor shortages, Volume 8 of the PROCEEDINGS of the Soil Science Society of America is now going into the mails. The volume contains the papers presented at the eighth annual meeting of the Society held in Cincinnati, Ohio, November 10 to 12, 1943, including a series of papers commemorating the one hundredth anniversary of the founding of the Rothamsted Experiment Station.

Doctor George D. Scarseth, formerly Head of the Department of Agronomy, Purdue University, Lafayette, Indiana, has resigned to become Director of Research of the American Farm Research Association. He will continue to reside in Lafayette, with headquarters at 300 Schultz Building.

—A—

Doctor Norman J. Volk, Head of the Department of Agronomy, Alabama Polytechnic Institute, Auburn, Alabama, has resigned to become Head of the Department of Agronomy at Purdue University, effective November 1.

—A—

Doctor Randall J. Jones, Associate Soil Chemist, Alabama Agricultural Experiment Station, Auburn, Ala., has resigned to accept a position with the Tennessee Valley Authority.

—A—

Doctor William A. Albrecht, Head of the Department of Soils, University of Missouri, was the principal speaker at the annual Florida Beef Cattle Field Day meetings held at Gainesville August 3 to 5. He spoke on soil fertility in its broader implications.

—A—

Doctor E. F. Gaines, Cerealist in the Agronomy Division, Washington Agricultural Experiment Station, and Professor of Genetics in Agronomy, State College of Washington, died on August 17, 1944, in Pullman. Doctor Gaines made outstanding contributions in wheat improvement and was a Fellow of the Society.

JOURNAL

OF THE

American Society of Agronomy

VOL. 36 OCTOBER, 1944 No. 10

THE INFLUENCE OF LESPEDEZA AND FERTILIZER TREATMENT ON THE BEHAVIOR OF DALLIS GRASS, CARPET GRASS, AND BERMUDA GRASS[1]

R. L. LOVVORN[2]

DALLIS grass, *Paspalum dilatatum* Poir., carpet grass, *Axonopus affinis* Chase, and Bermuda grass, *Cynodon dactylon* (L.) Pers., are the three most important permanent pasture grasses of the Coastal Plain of North Carolina. Even though farmers have observed that carpet grass is not entirely satisfactory for grazing, some states in the Coastal Plain of the southeastern United States have continued to recommend it. Studies in the lower Coastal Plain of North Carolina have shown that Dallis grass is more responsive to nitrogen fertilization than carpet grass (5).[3] Most carpet grass pastures in the state have a small legume population. Additional information is needed on the ability of various legumes to grow in association with these grasses and on the effects of different fertilizer treatments on the yield and botanical composition. The studies herein reported were designed to measure the seasonal and total yields of three important southern pasture grasses with and without legumes and to follow the population changes from year to year under different fertilizer treatments.

METHODS

The study was begun in the spring of 1937 on a Norfolk fine sandy loam soil and continued through 1942. This soil type is well drained and occupies an extensive area of the upper Coastal Plain. The original pH value was approxi-

[1]Contribution from the Department of Agronomy, North Carolina Agricultural Experiment Station, Raleigh, N. C., and the Division of Forage Crops and Diseases, Bureau of Plant Industry, Soils and Agricultural Engineering, Agricultural Research Administration, U. S. Dept. of Agriculture. Part I of a thesis submitted to the graduate faculty of the University of Wisconsin in partial fulfillment of the requirements for the Ph.D. degree. Published with the approval of the Director of the North Carolina Experiment Station as paper No. 189 of the Journal Series. Received for publication May 13, 1944.

[2]Associate in Agronomy (Forage Crops). The writer expresses his appreciation to H. L. Ahlgren and B. M. Duggar of the University of Wisconsin for their suggestions during the investigation. Appreciation is also expressed to members of the Department of Experimental Statistics, North Carolina Agricultural Experiment Station, for assistance in the analysis and interpretation of the data.

[3]Figures in parenthesis refer to "Literature Cited", p. 802.

mately 5.5. At the end of the experiment the unfertilized soil had a pH of 5.5, an exchange capacity of 2.43, exchangeable bases of 0.73, and 30% base saturation.

A split plot design was used in which the fertilizer treatments were the whole plots, and the seeding mixtures were the subplots. Three replications were used. Fertilizers treatment consisted of O, P, PK, NPK, PKCa, and NPKCa, respectively.[4]

Seedings made in March, 1937, consisted of various combinations of grasses and legumes. From these, the following were selected for detailed studies:

20 pounds Dallis grass
10 pounds Kobe lespedeza, *Lespedeza striata* (Thunb.) H. and A.

20 pounds Dallis grass

20 pounds carpet grass
10 lbs. Kobe lespedeza

20 pounds carpet grass

20 pounds Bermuda grass
10 pounds Kobe lespedeza

20 pounds Bermuda grass

7 pounds Dallis grass
7 pounds carpet grass
7 pounds Bermuda grass
5 pounds Kobe lespedeza
1 pound white clover, *Trifolium repens* L.
5 pounds hop clover, *Trifolium procumbens* L.

The vegetation was cut to a height of 1 inch approximately once each month during the growing season. The yields are reported as pounds of air dry matter per acre. Botanical analyses were made during the spring and fall of each year by means of the inclined point quadrat as designed by Tinney, *et al.* (11). Counts were made at 10 locations on each 4×30 foot plot, and the data recorded as the number of hits per plot. The weed population was less than 10% of the total population in all plots, and the data are not included in the botanical analyses.

RESULTS

TOTAL YIELDS

The average annual yield for the period 1938–42, inclusive, for each of the seven seedings under the various fertilizer treatments are given in Table 1. The data indicate clearly that the combination of each of the grasses with lespedeza was superior in yield to the grasses alone. The yields of Dallis grass and Bermuda grass were approximately the same when all fertilizer treatments were averaged; the yield of carpet grass was less. When grown in pure stands, Dallis grass was the only grass that responded to the PK treatment. The yields of all pure stands of grasses were more than doubled by applications of 300 pounds of nitrate of soda annually. The yield of carpet grass was not as large as the other grasses under any fertilizer treatment.

There was a tendency for the yield of Dallis grass-lespedeza to be less than Bermuda grass-lespedeza at the lower level of fertility and greater at the higher fertility levels. However, the differences between

[4]N = 300 pounds nitrate of soda annually (200 pounds in the spring and 100 pounds in the fall); P = 800 pounds superphosphate every 4 years; K = 200 pounds muriate of potash every 4 years; Ca = 2 tons dolomitic limestone applied at the beginning of the experiment.

the yields from the two seedings were not large enough for statistical significance under all fertilizer treatment comparisons. Regardless of treatment, the yields of carpet grass-lespedeza were less than either Dallis grass-lespedeza or Bermuda grass-lespedeza. The combination of the three grasses with three legumes behaved similarly to carpet grass-lespedeza under the treatments receiving mineral fertilizers without nitrogen and to Dallis grass-lespedeza under the nitrogen treatments.

TABLE 1.—*Yields of dry matter in pounds per acre of grasses with and without legumes and with various fertilizer treatments, average annual yield, 1938–42.*

Seedings	Fertilizer treatment						Average
	O	P	PK	NPK	PKCa	NPKCa	
Dallis-lespedeza	1,731	2,118	2,743	2,876	2,365	2,717	2,425
Dallis	917	1,005	1,158	2,158	1,032	1,911	1,363
Carpet-lespedeza	1,294	1,804	1,982	2,245	1,778	2,288	1,899
Carpet	731	740	725	1,695	686	1,586	1,027
Bermuda-lespedeza	1,871	2,205	2,067	2,676	2,229	2,464	2,252
Bermuda	982	946	918	2,269	938	2,126	1,363
Dallis-carpet-Bermuda-legumes	1,661	1,834	1,979	2,706	1,996	2,697	2,146
Average	1,312	1,522	1,653	2,375	1,575	2,256	1,782

The least significant difference:

	1% level	5% level
Between fertilizer treatments	108	76
Between seedings	79	60
Between seedings within any fertilizer treatment	194	146
Between fertilizer treatments with any seeding	202	152

Superphosphate increased the yield of the grass-lespedeza combinations. The over-all response of grass-lespedeza combinations to muriate of potash was highly significant, even though the treatment had no effect on the yield of Bermuda grass-lespedeza. Applications of nitrogen resulted in increases in the total yield of all grass-lespedeza combinations, although the increase was not significant with Dallis grass-lespedeza. The response of grass-lespedeza combinations to applications of nitrogen was less than that of the pure seedings of grasses. Limestone did not increase yields in any of the seedings.

SEASONAL YIELDS

Since the monthly yields of the different seedings were somewhat similar with all treatments where nitrogen was not included, the yields from the no-nitrogen treatments are combined in Table 2 and those for the nitrogen treatments in Table 3.

With the no-nitrogen treatments, the grasses with legumes produced greater yields every month of the growing season than did the grasses without legumes, even though lespedeza did not contribute directly to the yield during April and May. There was a tendency for the plots containing both Bermuda grass and lespedeza to make more growth during April and May than any other seeding. The Dallis grass-lespedeza seeding combination produced more growth during

TABLE 2.—*Monthly yields of dry matter in pounds per acre of grasses with and without legumes and grown at a low nitrogen level, average of O, P, PK, and PKCa treatments, 1938–42.*

Seedings	Seasonal yield						
	April	May	June	July	August	September	Total
Dallis-lespedeza	153	163	349	481	534	558	2,238
Dallis	81	80	122	204	256	284	1,027
Carpet-lespedeza	162	176	315	296	392	374	1,715
Carpet	87	95	134	98	153	154	721
Bermuda-lespedeza	185	240	402	387	464	415	2,093
Bermuda	107	149	169	141	199	180	945
Dallis-carpet-Bermuda-legumes	183	195	316	349	421	403	1,867
Average	137	157	258	279	346	338	1,515
1% level*	56	56	59	59	59	59	
5% level	41	41	44	44	44	44	

*The least significant difference between seedings.

July, August, and September than any other seeding. This was due to the fact that both species made their greatest growth during the latter months of the growing season and that lespedeza grew better in association with Dallis grass than with either of the other two grass species.

All yields of the pure grass seedings were low during April, May, and June when grown at a low-nitrogen level. The yields were approximately the same for all of the species during April and June. Since Dallis grass made its greatest growth from July through

TABLE 3.—*Monthly yields of dry matter in pounds per acre of grasses with and without legumes and grown at a high nitrogen level, average of NPK and NPKCa treatments, 1938–42.*

Seedings	Seasonal yield						
	April	May	June	July	August	September	Total
Dallis-lespedeza	148	302	496	597	593	662	2,798
Dallis	103	233	395	419	399	485	2,034
Carpet-lespedeza	222	356	460	338	464	426	2,266
Carpet	148	309	424	198	261	300	1,640
Bermuda-lespedeza	197	426	700	313	461	473	2,570
Bermuda	185	427	643	231	345	367	2,198
Dallis-carpet-Bermuda-legumes	281	437	577	415	474	518	2,702
Average	183	356	528	359	428	462	2,316
1% level*	79	84	84	84	84	84	
5% level	58	63	63	63	63	63	

*The least significant difference between seedings.

September, its yield was always greater than was that of the other two grasses during that period.

A comparison of the data in Tables 2 and 3 shows that nitrogen stimulated the growth of grasses slightly during April and considerably during May. Bermuda grass, with and without lespedeza, produced more forage than any other seeding during May and June when grown at a high-nitrogen level. The data in Table 3 show that the Dallis grass-lespedeza combination produced much more growth during July, August, and September than any other seeding.

The monthly distribution of yields from the seedings was not greatly affected by applications of nitrogen. Dallis grass, alone and with lespedeza, made its greatest growth from July through September, regardless of the nitrogen level. Seedings of Bermuda grass with lespedeza and of Dallis-carpet-Bermuda grass with legumes produced their greatest yields from June to September at a low-nitrogen level. Under the high-nitrogen level there was a tendency for these seedings to produce as much during May as during any other month. The greatest stimulation from nitrogen was obtained in May and June.

BOTANICAL COMPOSITION

The botanical composition was determined in the spring and fall of each year, beginning in the fall of 1937. The data in Table 4, therefore, represents counts in the fall of 6 years and in the spring of 5 years. Counts were made on three of the six fertilizer treatments and are listed as the frequency of the total hits of desirable species, i.e., the data from the Dallis grass seedings represent only grass, whereas, for the Dallis grass-lespedeza combination the total of the two species is included.

TABLE 4.—*Total hits of desirable species with various fertilizer treatments.*

Seedings	Spring analyses, 1938–42 average				Fall analyses, 1937–42 average			
	O	PKCa	NPKCa	Average	O	PKCa	NPKCa	Average
Dallis-lespedeza	131	192	231	185	201	272	244	239
Dallis	83	97	214	131	100	116	181	132
Carpet-lespedeza	152	171	199	174	272	276	280	276
Carpet	108	127	198	144	194	202	237	211
Bermuda-lespedeza	190	224	258	224	254	276	287	273
Bermuda	141	148	246	178	178	195	243	206
Dallis-carpet-Bermuda-legumes	185	218	257	220	266	273	268	269
Average	141	168	229	179	209	230	249	229

The least significant difference:

	Spring 1% level	Spring 5% level	Fall 1% level	Fall 5% level
Between fertilizer treatments	17	13	20	15
Between seedings	26	19	31	23
Between seedings within fertilizer treatments	44	33	53	40

These data show that the frequency of the hits was greatly increased by the presence of legumes, when all fertilizer treatments are averaged. That the density of all grass-legume combinations was greater in the fall than in the spring was due primarily to the greater growth of lespedeza in September than in June.

Although there was a tendency for the pure stands of grasses to be more dense when fertilized with the PKCa, the differences were in most cases not significant; the response to nitrogen was always highly significant. The percentage increase in total number of hits on the NPKCa as compared to the PKCa treatment was 121 for Dallis grass, 56 for carpet grass, and 66 for Bermuda grass in the spring. The corresponding percentage increases in the fall were 56, 17, and 25.

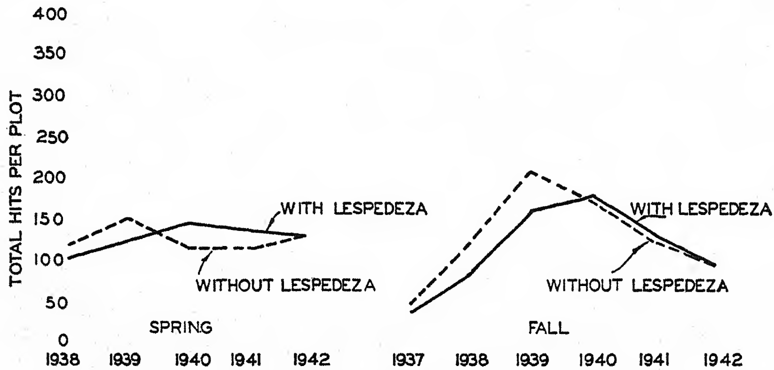


FIG. 1.—Total hits of Dallis grass when grown alone and in association with lespedeza.

The grass-lespedeza swards were greatly affected by the PKCa treatment. The percentage increase in the spring was 46, 12, and 18 for Dallis grass-lespedeza, carpet grass-lespedeza, and Bermuda grass-lespedeza, respectively. Botanical analyses in the fall showed percentage increases of 35, 1, and 9 for the corresponding swards. Data in both spring and fall show that the Dallis grass-lespedeza seeding was more responsive to the PKCa treatment than the other two grass-lespedeza combinations. This would indicate that lespedeza grows better in association with Dallis grass than with the other two grasses. The data in Table 4 also show greater differences between Dallis grass-lespedeza and Dallis grass than is true for either carpet grass or Bermuda grass compared with the grass-lespedeza combination. Lespedeza grew better in association with Bermuda grass than with carpet grass.

A slight increase in the density of the grass-lespedeza seedings when fertilized with nitrogen in addition to PKCa was found only in the spring. The data in Table 4 show, therefore, that the stimulating effect of nitrogen on grasses were accomplished with a corresponding reduction in the quantity of lespedeza.

In order to study the effect of lespedeza and fertilizer treatments on the development of the grasses, comparisons were made between the

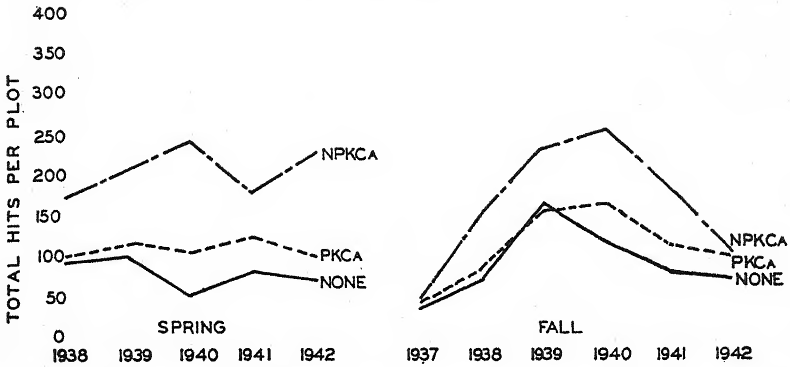


FIG. 2.—Total hits of Dallis grass with various fertilizer treatments.

grasses grown alone and with lespedeza. The data for Dallis grass are given in Table 5 and Figs. 1 and 2. These data show that the density of stand of Dallis grass was not influenced by lespedeza when all fertilizer treatments were combined. The data for the individual years, however, indicate that lespedeza depressed the density of grass in 1938 and 1939 and increased it during the spring of the next 2 years. Stands of both Dallis grass and carpet grass were reduced

TABLE 5.—*Total hits of grass when grown alone and in association with lespedeza with various fertilizer treatments.*

Seedings	Spring analyses, 1938–42 average				Fall analyses, 1937–42 average			
	O	PKCa	NPKCa	Average	O	PKCa	NPKCa	Average
Dallis Grass								
With lespedeza......	79	121	200	133	89	114	150	117
Without lespedeza...	83	97	214	131	100	116	181	132
Average............	81	109	207	132	94	115	165	125
Carpet Grass								
With lespedeza......	100	118	171	130	175	170	203	183
Without lespedeza...	108	127	198	144	194	202	237	211
Average............	104	122	184	137	184	186	220	197
Bermuda Grass								
With lespedeza......	138	161	232	177	155	164	232	184
Without lespedeza...	141	148	246	178	178	195	243	206
Average............	139	154	239	178	166	179	237	195

The least significant difference at 5% level:

	Dallis Spring	Dallis Fall	Carpet Spring	Carpet Fall	Bermuda Spring	Bermuda Fall
Between fertilizer treatments................	17	20	19	27	20	30
Between seedings...........................	14	16	15	22	16	24
Between seedings within fertilizer treatments...	24	28	27	38	28	42

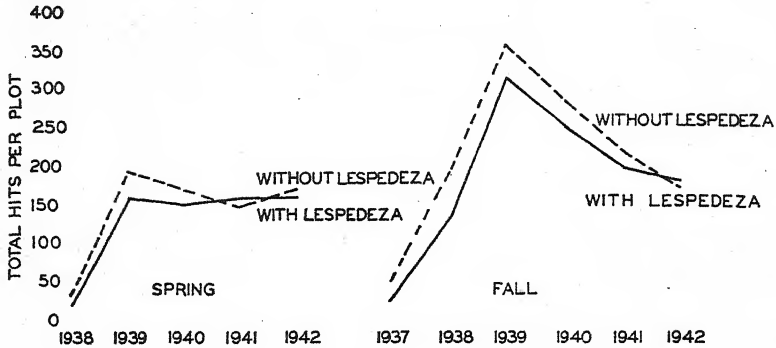


FIG. 3.—Total hits of carpet grass when grown alone and in association with lespedeza.

during the winter of 1939–40 because of winter injury. Both grasses were injured less when grown in association with lespedeza (Figs. 1 and 3). The data in Table 5 show that response of Dallis grass to PKCa was significant when it was grown in association with lespedeza, whereas the response was slight and not considered to be statistically significant when grown in pure stands. Conversely, the response to nitrogen was less when Dallis grass was grown in association with lespedeza.

It is apparent from Fig. 2 that fertilizer treatments had a pronounced effect on the density of Dallis grass following the severe winter of 1939–40. Prior to that time the PKCa treatment had little effect on the stand. The effects of nitrogen on stands, although pronounced in all years, was much greater during years of favorable rainfall. The rainfall was approximately normal for the spring of 1942 but below normal during the corresponding period of 1941.

The data in Table 5 indicate that there was a tendency for carpet grass to be depressed when grown in association with lespedeza. The density of carpet grass, when grown with lespedeza, was approximately the same in the springs of 1939 and 1940 (Fig. 3). The density

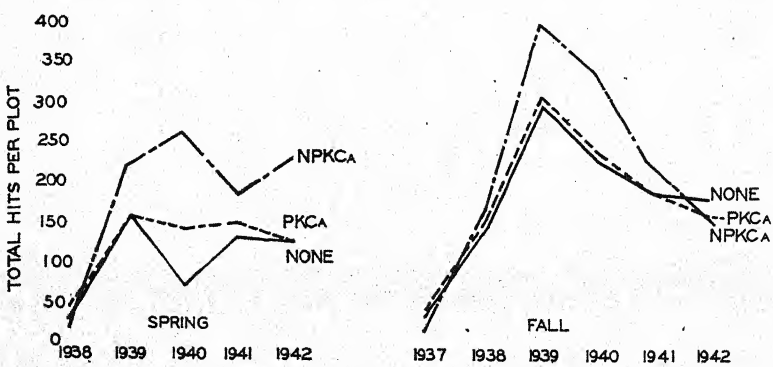


FIG. 4.—Total hits of carpet grass with various fertilizer treatments.

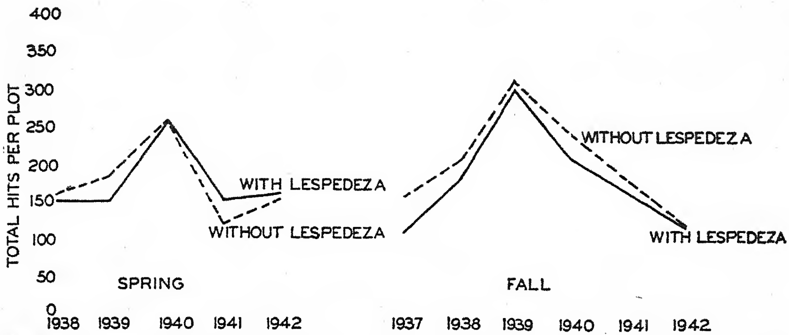


FIG. 5.—Total hits of Bermuda grass when grown alone and in association with lespedeza.

of carpet grass, when grown alone, was less during 1940, indicating the beneficial effect of lespedeza in minimizing winter injury. Contrary to the behavior of Dallis grass, there was no tendency for the carpet grass to respond more to PKCa when grown with lespedeza than when grown alone.

Data which appear in Fig. 4 show that the extent of the reduction of the stand of carpet grass by winter killing was also inversely related to soil fertility levels. The stand was reduced to a greater extent on the unfertilized land than was observed for Dallis grass. As was true for Dallis grass, the differences between carpet grass grown at different nitrogen levels were greater during seasons of adequate rainfall.

It is evident from the data in Table 5 that lespedeza did not affect the density of Bermuda grass in the spring when all fertilizer treatments were averaged. There was a tendency for the density of the Bermuda grass to be greater in pure stands than in association with lespedeza, in the fall, although the reductions were not always statistically significant (Fig. 5). The difference between the Bermuda grass, when grown with lespedeza, unfertilized and fertilized with

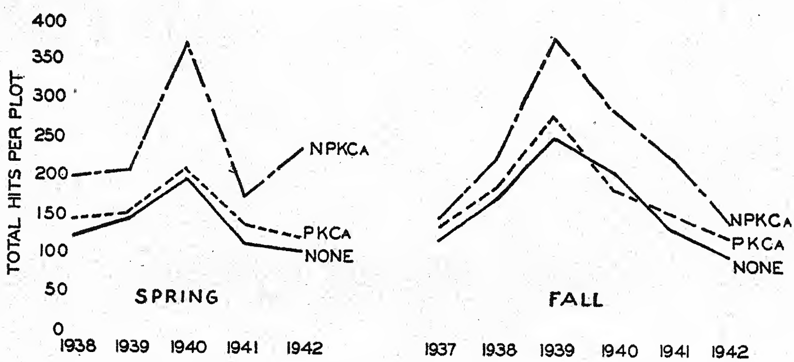


FIG. 6.—Total hits of Bermuda grass with various fertilizer treatments.

PKCa, is significant in the spring. Since the pure stands of this grass did not respond to PKCa fertilizer, it would appear that the lespedeza enabled the grass to use the fertilizer more efficiently or that the grass benefited directly from its association with the legume. Bermuda grass made more growth in the spring of 1940 than in 1939 with all fertilizer treatments (Fig. 6). This behavior was not true for the other two grasses except when fertilized with nitrogen. These data substantiate the observation that no reduction occurred in the stand of this species following the severe winter of 1939–40.

DISCUSSION

Under the conditions of this experiment, Dallis grass and Bermuda grass have produced greater yields than carpet grass. Mayton (6), reporting results from a similar soil in Alabama, states that of the three grasses, Dallis produced the largest yields and Bermuda grass the smallest. He also found carpet grass to be more susceptible to drought than Dallis grass. Stephens (9) states that both Dallis grass and carpet grass require moist soil. In this experiment, carpet grass established an excellent sod on the well-drained soil, although the yield was less than from the other two grasses.

The results from the plant population studies indicate that lespedeza grows better in association with Dallis grass than with either carpet grass or Bermuda grass. Since Dallis grass is a semi-bunch grass, it would be expected to be more tolerant of other species. This observation is in agreement with Stephens (9). Mayton (6), on the other hand, found lespedeza to grow better in combination with Bermuda grass than with Dallis grass.

Pure stands of Dallis grass responded to applications of superphosphate and potash; carpet grass and Bermuda grass did not. Bledsoe and Sell (1) state that Dallis grass gave a medium response to calcium and phosphorus, whereas carpet grass and Bermuda responded only slightly. Mayton (6) also observed that Dallis grass responded to lime, but he did not grow the grass in pure stands. In the experiments herein reported no response to lime was noted, either for grasses or grasses and lespedeza. The soil on which this study was conducted had been relatively heavily fertilized for a number of years prior to the initiation of the experiment and apparently the fertilizer contained sufficient calcium for the grasses and lespedeza. White clover did respond to lime, however. Other data from the Coastal Plain of North Carolina indicate a response to limestone only when the sward includes a legume. Legumes are usually stimulated by applications of mineral fertilizers. Their ability to fix nitrogen is later reflected in increased total yield of the legumes and grasses. Such ecological relationships have been observed by many workers (2, 4, 7, 8, 10).

Data which have been presented show significant increases in both the yield and density of sward of pure stands of grasses following applications of commercial nitrogen. Since larger yields were obtained with grass-legume combinations, however, it would appear that the fertilizer treatment should be one that would increase the growth of

these seedings. The increases, measured either in yield or density of sward, resulting from applications of nitrogen to grass-lespedeza seedings were small. The botanical data show that the increased growth of the grass resulted in less lespedeza in the sward. Similar behavior has been observed for other species (2, 3, 8, 13).

Brown and Munsell (2) found that applications of nitrogen resulted in the greatest increase during the zenith of growth period, May 15 to June 15, and that summer applications were about half as effective as spring applications of nitrogen. Mayton (6) concluded that regardless of the fertilizer materials used, yields follow the same general seasonal distribution and that they were correlated with a 20-day lag in rainfall. Yields during April and May were greatly increased by applications of nitrogen to species used in this study. The writer (5) has found low hop clover to be a much more effective way of obtaining larger yields in the spring.

The range of Bermuda grass extends somewhat farther north than Dallis grass or carpet grass, according to Vinall and Hein (12). The minimum temperatures during January at Smithfield,[5] North Carolina, for the period 1938 to 1942, inclusive, were as follows: 1938, 15° F; 1939, 16° F; 1940, 3° F; 1941, 15° F; 1942, 6° F. No winter-killing occurred in 1942, even though the minimum temperature was within 3 degrees of the minimum in 1940. The low temperature in 1940 was accompanied by a mean temperature of 31.6°F for the month of January, whereas the average for the same month in 1942 was 40.6° F. Increasing the fertility of the soil either directly with commercial fertilizer or indirectly through the growing of legumes, enables Dallis grass and carpet grass to tolerate colder temperatures, a fact of considerable economic importance in areas of higher altitude in North Carolina.

SUMMARY

Seedings of Dallis grass, carpet grass, and Bermuda grass were established on a Norfolk fine sandy loam soil under six fertilizer treatments in the spring of 1937. The fertilizer treatments, in addition to the untreated areas, were (a) superphosphate; (b) superphosphate and muriate of potash; (c) nitrate of soda, superphosphate, and muriate of potash; (d) superphosphate, muriate of potash, and limestone; and (e) nitrate of soda, superphosphate, muriate of potash, and limestone. The superphosphate and muriate of potash were applied at the rates of 800 pounds and 200 pounds per acre, respectively, every four years. Annual applications of nitrate of soda were made at the rate of 300 pounds per acre. Two tons per acre of limestone were used. The herbage was harvested once each month during the growing period. Botanical analyses were made in the spring and fall of each year with the inclined point quadrat.

The results from the field study for the period 1937 to 1942, inclusive, may be summarized as follows:

1. A mixture of Dallis grass and lespedeza produced higher yields than any other seedings when commercial nitrogen was applied.

[5]Smithfield is about 4 miles from the location of the experiment.

2. Bermuda grass-lespedeza produced as much herbage as did Dallis grass-lespedeza on the unfertilized plots.

3. Mixtures of each of the grasses and lespedeza produced larger yields than the grasses alone.

4. Bermuda grass seedings, with and without lespedeza, produced more herbage than the corresponding seedings of Dallis grass from April through June.

5. Heavy applications of nitrogen stimulated the grasses. The resulting increase in competition from the grasses reduced the stand of lespedeza.

6. Applications of mineral fertilizer exclusive of nitrogen had little effect on the density of the grasses except where winterkilling occurred.

7. Applications of fertilizer and the presence of lespedeza decreased the extent of winterkilling of Dallis grass and carpet grass. No winterkilling of Bermuda grass occurred.

8. The density of the stand of Dallis grass and Bermuda grass was affected more by applications of a complete fertilizer than was the stand of carpet grass.

LITERATURE CITED

1. Bledsoe, R. P., and Sell, O. E. Permanent pastures. Ga. Agr. Exp. Sta. Bul. 207. 1940.
2. Brown, B. A., and Munsell, R. I. Pasture investigations. Conn. (Storrs) Agr. Exp. Sta. Bul. 245. 1943.
3. Eheart, James F., and Ellet, W. B. The effects of certain nitrogenous fertilizers on the chemical and vegetative composition and yield of pasture plants. Va. Agr. Exp. Sta. Tech. Bul. 75. 1941.
4. Elton, E. C., La Master, J. P., and Mitchell, J. H. Permanent pasture studies. S. C. Agr. Exp. Sta. Bul. 308. 1937.
5. Lovvorn, R. L. The effects of fertilization, species competition, and cutting treatments on the behavior of Dallis grass, *Paspalum dilatatum* Poir., and carpet grass, *Axonopus offinis* Chase. Jour. Amer. Soc. Agron., 36: 590–600. 1944.
6. Mayton, E. L. Permanent pasture studies on upland soils. Ala. Agr. Exp. Sta. Bul. 243. 1935.
7. Prince, F. S., Percival, G. P., and Scripture, P. N. Pasture top dressing in New Hampshire. N. H. Agr. Exp. Sta. Bul. 320. 1940.
8. Robinson, R. R., and Pierre, W. H. Response of permanent pastures to lime and fertilizers. W. Va. Agr. Exp. Sta. Bul. 289. 1938.
9. Stephens, J. L. Pastures for the Coastal Plain of Georgia. Ga. Coastal Plain Exp. Sta. Bul. 27. 1942.
10. Sprague, H. B., Farris, N. F., and Cathcart, C. S. Improving pastures in New Jersey. N. J. Agr. Exp. Sta. Bul. 565. 1934.
11. Tinney, F. W., Aamodt, O. S., and Ahlgren, H. L. Preliminary report of a study on methods used in botanical analyses of pasture swards. Jour. Amer. Soc. Agron., 29:835–840. 1937.
12. Vinall, H. N., and Hein, M. A. Climatic adaptation of principal forage grasses of the United States. U. S. D. A. Yearbook, 1937:1041–1042. 1937.
13. Woodward, T. E., Shepherd, J. B., and Hein, M. A. The Hohenheim system in the management of permanent pastures for dairy cattle. U. S. D. A. Tech. Bul. 660. 1938.

TIME AND RATE OF SYNTHESIS OF PHYTIN IN CORN GRAIN DURING THE REPRODUCTIVE PERIOD[1]

ERNEST B. EARLEY AND ERNEST E. DETURK[2]

PHYTIC acid from plant materials has been shown (3, 24)[3] to be inosite hexaphosphoric acid. The mixed magnesium, calcium, and potassium salt of this acid is termed phytin (6). Phytin is the naturally occurring principal storage form of phosphorus in all seeds thus far investigated (6, 10, 14, 15, 22). It has also been found in the vegetative parts of a few species of grass (13), in wheat straw (14), and in the underground portion only of carrots, parsnips, potatoes, and Jerusalem artichokes (15). With regard to the corn plant, DeTurk, *et al.* (10) found that the only parts to contain phytin are the grains or kernels, beginning about 2 weeks after fertilization. They were unable to find phytin in the stalk, leaves, tassel, shank, or cob at any stage of development or in the pistillate structure prior to pollination. The literature (5) indicates doubt that corn pollen contains phytin, although inorganic phosphorus and inosite are present in ample quantities.

With these facts in mind, DeTurk, *et al.* (10) made the following statement in 1932 with regard to the formation of phytin in corn ovules: "The accepted reversibility of enzyme reactions (see Bayliss (7), Chapter 5, for instance) considered with the undisputed enzymatic cleavage of phytin by phytase (1, 2, 8, 16, 21) leaves no doubt that phytin synthesis is an enzyme reaction. Furthermore, the fact that the beginning of this synthesis follows immediately after pollination and does not occur before pollination suggests an intimate association of activation of the zymogen with fertilization of the ovule. Inasmuch as extremely small quantities of an activator may be sufficient to set off a progressive enzyme reaction, it is not beyond the range of possibility that the pollen grain may serve as the carrier of this activator."

In view of the results reported by these investigators on the phytin problem, it appeared desirable to follow the course of phytin synthesis in developing corn grain from before pollination to maturity, with special emphasis on the 2-week period immediately following pollination. This study, therefore, was undertaken for the purpose

[1]Contribution from the Department of Agronomy, Agricultural Experiment Station, University of Illinois, Urbana, Ill. Published with the approval of the Director and of the Dean of the Graduate School. The major part of this work was included in a thesis submitted by the senior author in partial fulfillment of the requirements for the Ph.D. degree in the Graduate School. Received for publication July 3, 1944.

[2]Assistant Agronomist, Division of Forage Crops and Diseases, Bureau of Plant Industry, Soils and Agricultural Engineering, Agricultural Research Administration, U. S. Dept. of Agriculture; formerly, First Assistant in Soil Fertility, Department of Agronomy, University of Illinois; and Professor of Soil Fertility, University of Illinois, respectively. The authors greatly appreciate the aid of K. M. Peng, First Assistant in Soil Fertility, University of Illinois, who carried out some of the chemical analyses.

[3]Figures in parenthesis refer to "Literature Cited", p. 813.

of following chemically the synthesis of phytin in corn grain in an attempt to establish its initial synthesis and also to determine its rate of formation in the unpollinated pistillate structure and thereafter to the mature grain stage. A second purpose was to determine the relation of phytin phosphorus to total phosphorus and the rate of phosphorus movement into the corn grain throughout this period.

PROCEDURE

COLLECTING AND PRESERVING SAMPLES

Station Reid Yellow Dent corn[4] was used for this investigation. Each day during the active shooting period shoot bags were put on a large number of normally developing shoots on which no silks were visible. When the silks were ready to be pollinated, the controlled pollination and sampling schedule was begun. The schedule is given in Table 1.

The first sample consisted of 24 unpollinated ears selected at random from the bagged shoots at 10:00 a.m. July 20, 1939. At 8:00 a.m. the same day 48 ears were pollinated. These served for the second and third samples, representing intervals after pollination of 6 and 12 hours, respectively. From 5:00 to 7:30 p.m. July 20, all remaining bagged shoots were pollinated and marked. This large quantity of uniformly pollinated material supplied samples for the period from July 21 to August 3 during which time samples were taken daily except for the last few days. From August 10 to September 28 weekly samples were selected at random from naturally pollinated ears.

All samples, except the fully mature ones, were brought from the field to the laboratory in moist burlap sacks and preserved within 3 hours after being picked. Each field sample was divided into three laboratory samples and each of these three groups was husked separately and divided into shanks, silks, cobs, and grains.[5] The grains were cut and then thoroughly scraped from the cobs into a clean, enameled pan.[6] The material was mixed and a weighed sample of about 50 grams placed into a tared 400-ml beaker and covered with 300 ml of boiling 95% alcohol without the addition of $CaCO_3$ (9). A sample for determination of moisture was taken at the same time. The remainder of the sample was rapidly dried in the steam-heated oven at 73° C with forced draft ventilation. The alcohol-plant mixture was boiled about 15 minutes, after which it was rapidly dried in the same oven at 73° C. Upon being removed from the oven the sample was covered with 95% alcohol, a petri dish placed over the beaker, and stored. The silks and pollen were preserved like the immature grains, while the cobs and shanks were dried in the steam oven. After the grain was sufficiently mature to shell, it was also rapidly dried in the steam oven at 73° C and stored in 1-pint glass jars with a few naphthalene balls. Dry weights are given in Table 1.

PREPARATION OF SAMPLES FOR ANALYSIS

The alcohol-preserved samples were prepared for analysis by drying for 12 hours in the forced draft steam oven at 53° C followed by 8 hours in a vacuum oven at 65° C. This treatment brought the samples to constant weight.

All materials not preserved in alcohol, and which had been previously dried in the steam oven at 73° C, were finely ground in a Wiley mill and dried to constant weight in a vacuum oven in preparation for chemical analysis.

CHEMICAL METHODS

Total phosphorus.—About 0.3-gram samples of the oven-dried portions of the corn grain were used for total phosphorus determinations. The samples were

---

[4]The writers wish to thank A. L. Lang, Assistant Chief in Soil Experiment Fields, University of Illinois, for making available the plot of corn used in this investigation.

[5]Entire pistillate structure minus silks in the earlier samples.

[6]Owing to the method of separation of fruits at the earlier stages of development, some material from the cob probably was included and may have influenced slightly the analytical values found for the ovules.

TABLE 1.—*Pollination and sampling schedule and dry weights of samples.*

Pollinated	No. of ears per field sample*	Date and time sampled, 1939	Interval between pollination and sampling	Total dry weight of grain, grams†	Average dry weight of grain per ear, grams†	Weekly gain or loss of grain per ear, grams†
Not pollinated	24	July 20, 10 a.m.	0	26.4	1.1	—
July 20, 8 a.m.	24	July 20, 2 p.m.	6 hrs.	26.7	1.1	—
July 20, 8 a.m.	24	July 20, 8 p.m.	12 hrs.	23.9	1.0	—
July 20, 5–7:30 p.m.	21	July 21, 7 p.m.	1 day	27.9	1.3	—
July 20, 5–7:30 p.m.	21	July 22, 7 p.m.	2 days	33.2	1.6	—
July 20, 5–7:30 p.m.	18	July 23, 7 p.m.	3 days	53.7	3.0	—
July 20, 5–7:30 p.m.	15	July 24, 7 p.m.	4 days	41.0	2.7	—
July 20, 5–7:30 p. m.	12	July 25, 7 p.m.	5 days	65.6	5.5	—
July 20, 5–7:30 p. m.	9	July 27, 7 p.m.	7 days	46.8	5.2	3.9
July 20, 5–7:30 p.m.	9	July 30, 7 p.m.	10 days	79.0	8.8	—
July 20, 5–7:30 p.m.	10	Aug. 3, 7 p.m.	2 weeks	134.5	13.4	8.2
About July 20, natural	9	Aug. 10	3 weeks	526.7	58.5	45.1
About July 20, natural	9	Aug. 17	4 weeks	974.3	108.2	49.7
About July 20, natural	9	Aug. 24	5 weeks	1,157.1	128.6	20.4
About July 20, natural	9	Aug. 31	6 weeks	1,143.3	127.3	−1.3
About July 20, natural	9	Sept. 7	7 weeks	1,551.0	172.3	45.0
About July 20, natural	9	Sept. 14	8 weeks	1,561.3	173.5	1.2
About July 20, natural	9	Sept. 21	9 weeks	1,461.3	162.4	−11.1
About July 20, natural	12	Sept. 28	10 weeks	1,797.1	149.8	−12.6

*Each field sample was divided into three laboratory samples, taking one third of the number of ears indicated in this column for each.
†Pistillate structure minus silks in earlier samples.

oxidized by a nitric-perchloric acid method developed by the authors for rapid destruction of 3 grams or less of plant tissue. The sample was placed in a 250-ml beaker and 10 ml of concentrated HNO_3 added, and stirred thoroughly into the material. Plant tissue adhering to the stirring rod was rinsed into the beaker with a minimum of distilled water and the rod removed. The time required to prepare a set of 10 beakers as directed, about 15 minutes, was sufficient for the HNO_3 to oxidize the easily oxidizable portion of the sample. Then 10 ml of distilled water were added slowly down the side of the beaker so as to form a layer beneath the acid-sample mixture. Ten ml of perchloric acid (70 to 72%) were then added in the same manner and the beaker placed on a cool gas hot plate, heated slowly, with cover glass, to boiling and boiled gently until all organic matter was destroyed. The beaker was removed, cooled, material on cover glass rinsed into it with distilled water, returned to the hot plate, and the contents slowly evaporated to dryness below the boiling point, without the cover glass. This procedure is not suitable for samples of more than 5 grams.

Following oxidation the residue was taken up in about 25 ml of 5% HNO_3 and heated on the steam bath for a half hour to convert meta-phosphoric acid to orthophosphoric acid. After hydrolysis, phosphorus was determined colorimetrically (11).

Phytin phosphorus.—The alcohol-preserved samples of the immature grains and the oven-dried samples of the more mature ones were used for the determination of phytin phosphorus. About 8 grams of material were used for each determination. Sugars were removed from these samples before determining phytin phosphorus by extracting them with 80% alcohol in a Soxhlet extractor for 16 hours. The sugar-free sample was then extracted 2 hours on a shaking machine with a solution of 1.2% HCl containing 10% anhydrous Na_2SO_4. The sample-solvent ratio was approximately 1:20. It was then either filtered with suction through a Gooch crucible with asbestos mat or centrifuged and filtered through a coarse filter paper. Fifty ml of the extract were pipetted into a 250-ml beaker and 50 ml of distilled water added, giving an HCl concentration of 0.6%. An excess (usually 15 ml total volume) of about 0.2% ferric chloride solution in 0.6% HCl was added while the solution was slowly stirred. After the ferric phytate had completely precipitated and settled, it was filtered onto a fine asbestos mat in a Gooch crucible by means of suction. The precipitate was rinsed from the beaker with a few small quantities of 0.6% HCl-Na_2SO_4 solution, after which it was washed five times on the filter with the same solution to remove nonphytin phosphorus compounds. The precipitate was moistened with a few drops of 50% magnesium nitrate solution, dried in the oven at 100° C, and ignited in the electric furnace for 1 hour at about 1,000° C. After cooling, the asbestos mat with the ignited precipitate was transferred to a 250-ml beaker and the precipitate dissolved in 10 ml of concentrated HCl. Water was added and the solution filtered into a 200-ml volumetric flask, made to volume, and total phosphorus determined colorimetrically (11). This value, expressed as percentage of sample, represents phytin phosphorus. A complete description of this method is given elsewhere (12).

TIME REQUIRED FOR PRECIPITATION AND SETTLING OF FERRIC PHYTATE

Since one of the major objects of this investigation was to ascertain the initial synthesis of phytin in the pistillate structure, it was necessary to learn the smallest quantity of phytin phosphorus that could be detected by this method. In order to do this, about 1 liter of corn meal extract was prepared as described above, using 5-gram batches. Portions of this solution were used for precipitating phytin. In each case the total volume was made to 115 ml and the iron added was 28.5 mgms. The results of this test are shown in Table 2. These results show that as little as 0.066 mgm of phytin phosphorus can be precipitated by this method if allowed to stand 96 hours. It may be possible that even less could be detected by allowing a longer settling time.

It has been shown (12) that excess iron, about 1.2 times the theoretical, will completely precipitate phytin, although 3.6 times the theoretical is required to form the fully saturated tetra ferric phytate. If extremely small amounts of phytin are present, however, the precipitate settles very slowly. As Table 2

shows, it would be incorrect to assume that phytin is absent if insufficient time is allowed for the ferric phytate to exhibit itself. Also, any phosphorus-containing precipitate which forms, regardless of the time factor, is ferric phytate. Wrenshall and Dyer (23) state that, so far as they have been able to discover, no organic phosphorus compound other than phytin forms a ferric salt that is insoluble in 0.6% HCl.

TABLE 2.—*Relation of quantity of phytin phosphorus to rate of ferric phytate formation and complete precipitation.*

Volume of extract, ml	Phytin phosphorus present, mgm	Time required for	
		Cloudiness, hrs.	Complete precipitation, hrs.
0.5	0.066	—	96.0
1.0	0.132	22.0	45.0
2.0	0.264	11.0	20.0
3.0	0.396	4.5	20.0
4.0	0.528	2.0	6.0
5.0	0.660	1.5	6.0
10.0	1.32	0.33	2.0
15.0	1.98	0.15	0.5
20.0	2.64	Immediately	0.25
25.0	3.30	Immediately	0.25
30.0	3.96	Immediately	0.25
50.0	6.60	Immediately	0.25

EXPERIMENTAL RESULTS

The percentages of total and phytin phosphorus found in the developing corn grain are recorded in Table 3 and shown in Fig. 1. The unpollinated ovules with associated structures contained 0.608% total phosphorus.[7] Those pollinated for 6- and 12-hour intervals showed only a slight decrease from the unpollinated sample. At the end of 1 day following pollination total phosphorus had decreased to 0.503% and remained close to this value to the 10th day after pollination. By the end of the second week after pollination the percentage of total phosphorus started to decline and continued to do so until the end of the fourth week. From this time until maturity it remained unchanged.

The phytin data show that the ovules with surrounding structures before pollination and up to 2 weeks thereafter contained very little phytin phosphorus. The average for this period was 0.014% and the minimum 0.002%. The latter percentage represented 0.068 mgm of phytin phosphorus in the aliquot used, essentially the same amount as the minimum found to be detectable (Table 2). This is the first recorded instance, so far as the authors are aware, of the finding of phytin phosphorus in the unfertilized ovule or surrounding tissues. Its detection here as against previous failures may be attributed to the use of a much more sensitive method for its detection than was

[7]See footnote 6, p. 804.

TABLE 3.—*Percentage of total and phytin phosphorus in developing corn grain.*

Interval after pollination	Phosphorus		Av. percentage		Percentage nonphytin phosphorus	Phytin phosphorus as percentage of total phosphorus
	Total %	Phytin %	Total P	Phytin P		
Unpollinated....	0.615* 0.601	0.008 0.017	0.608	0.013	0.595	2.1
6 hours.........	0.565 0.537	0.005 0.018	0.551	0.012	0.539	2.2
12 hours........	0.531 0.674	0.015 0.015	0.602	0.015	0.587	2.5
1 day...........	0.495 0.512	0.013 0.013	0.503	0.013	0.490	2.6
2 days..........	0.443 0.529	0.013 0.011	0.486	0.012	0.474	2.5
3 days..........	0.460 0.496	0.007 0.018	0.478	0.013	0.465	2.7
4 days..........	0.513 0.477	0.009 0.016	0.495	0.012	0.483	2.4
5 days..........	0.484 0.483	0.002 0.066	0.484	0.034	0.450	7.0
7 days	0.484 0.472	0.003 0.005	0.478	0.004	0.474	0.8
10 days.........	0.518 0.466	0.012 0.066	0.492	0.009	0.483	1.8
2 weeks.........	0.421 0.430	0.007 0.027	0.426	0.017	0.409	4.0
3 weeks.........	0.343 0.304	0.107 0.121	0.323	0.114	0.209	35.3
4 weeks.........	0.288 0.304	0.157 0.146	0.296	0.152	0.144	51.3
5 weeks.........	0.324 0.302	0.205 0.188	0.313	0.197	0.116	62.9
6 weeks.........	0.324 0.312	0.214 0.204	0.318	0.209	0.109	65.7
7 weeks.........	0.312 0.281	0.273 0.241	0.297	0.257	0.040	86.5
8 weeks.........	0.285 0.304	0.248 0.262	0.295	0.255	0.040	86.4
9 weeks.........	0.312 0.299	0.270 0.272	0.305	0.271	0.034	88.8
10 weeks........	0.320 0.296	0.278 0.263	0.308	0.271	0.037	88.0

*The duplicates are separate sets of ears from the same sampling date and the difference between duplicates therefore includes natural variation in the plant material as well as experimental error of the chemical determination. The differences between duplicates are insignificant, as is indicated by the value t, which was found to be 0.51 as compared to 2.10 for the 5% level.

available in earlier investigations. By the end of the third week after pollination, rapid synthesis of phytin was under way and proceeded through the fifth week, at which time the percentage of phytin phosphorus was 0.197. There was very little metabolic activity during the sixth week, whereas by the end of the seventh week phytin phosphorus had increased to 0.257% where it remained with little further change to the tenth and final sampling period.

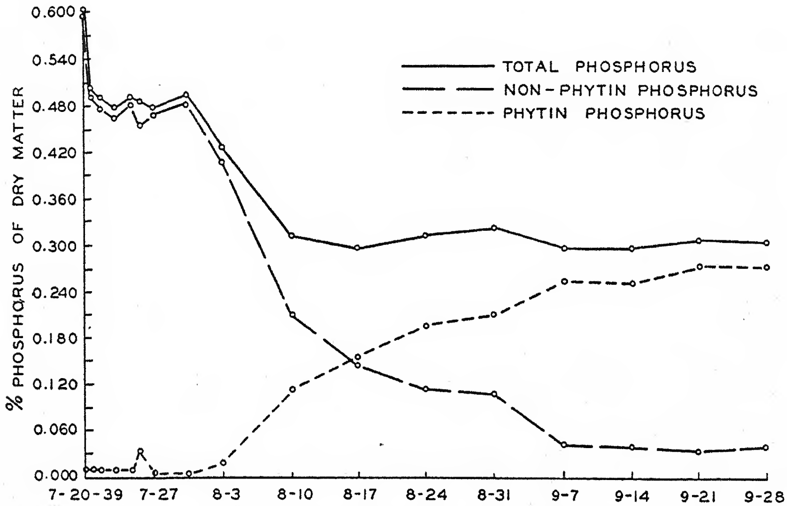


FIG. 1.—Percentage of total phytin and nonphytin phosphorus in corn grain from pollination to maturity. July 20 values represent unpollinated ovules with associated tissues.

DISCUSSION OF THE PHOSPHORUS DATA

The phosphorus data show two facts of considerable interest. The first is that the developing corn grain requires a supply of available phosphorus from pollination until the grain is essentially filled—a period of about 7 weeks in this case. The near cessation of physiological activity in the sixth week will be considered in a subsequent paper. The second fact is that the phosphorus metabolism of the grain falls, in a general way, into two types. The first type consists of the formation of the entire cellular structure of the fruit with its full complement of nonlabile phosphorus during the first 4 weeks after pollination, at the end of which time it is essentially complete. The second type consists of the formation of phytin. This latter reaction proceeds simultaneously with the first type during the third and fourth weeks and then becomes the dominant, if not the only, phosphorus reaction through the fifth, sixth, and seventh weeks, at the end of which time phosphorus metabolism is essentially complete.

A similar trend of events may be discerned in the studies of the wheat plant reported by Knowles and Watkins (14), except that phytin phosphorus constituted only 49.3% of the total phosphorus in the

wheat grain at maturity as against 88.0% in the corn grain of this investigation (Fig. 2). Webster (22), Rather (20), and DeTurk, *et al.* (10) have reported corresponding values for corn grain ranging from 67 to 83%.

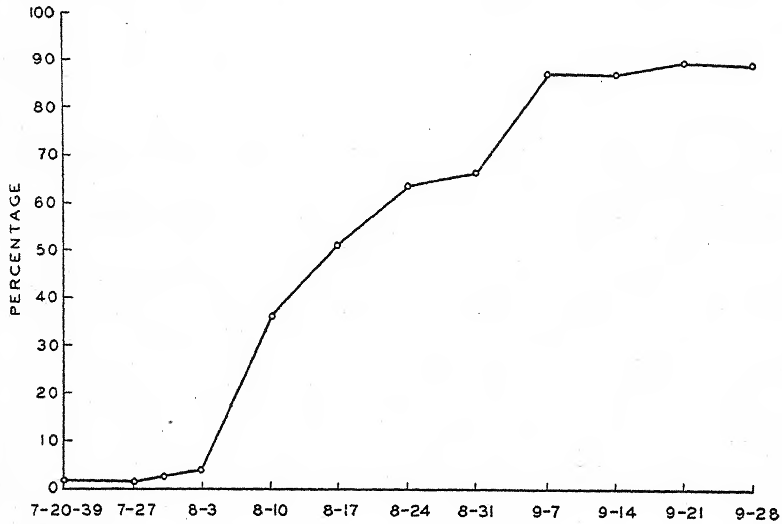


FIG. 2.—Phytin phosphorus as percentage of total phosphorus in developing corn grain at weekly intervals from pollination to maturity. July 20 values represent unpollinated ovules with associated tissues.

During this latter period, the fifth through the seventh week, phytin is synthesized at the expense of all the newly translocated phosphorus plus a portion of the nonphytin phosphorus already present in the grain. For example, during the seventh week, 177 mgms of phytin phosphorus were formed per ear of grain from 71 mgms of nonphytin phosphorus, already present in the ovules, and 106 mgms of newly translocated phosphorus. A question arising from this observation is whether this phosphorus newly translocated into the grain represents recently absorbed phosphates from the soil or whether it represents phosphates stored in the plant tissues during the absorption phase of the vegetative period.

The available data on this point seem to indicate that the corn plant does not or cannot store a sufficient supply of phosphorus within its tissues during the vegetative period to carry the plant to maturity in a normal condition. In an earlier investigation by the junior author corn plants were grown in sand culture with a concentration of 28 p.p.m. of phosphorus as KH_2PO_4 in the culture solution for 49 days after planting. Completely depriving these plants of phosphate then, which was shortly before shooting, resulted in the formation of small nubbins bearing a few grains on some plants and no shoots at all on others. Similar plants, which received 28 p.p.m. of phosphorus continuously, produced normal ears similar to those of

field-grown corn. A similar behavior appears to be true of the soybean plant. In this research, conducted by the senior author, soybean plants which received 31 p.p.m. of phosphorus as KH_2PO_4 for 52 days after planting, until pods were forming, produced less seed per plant and seed of a much lower total phosphorus percentage than those receiving 31 p.p.m. of phosphorus continuously. Apparently then, corn and soybean plants, and perhaps others, require an available supply of soil phosphorus for a somewhat longer period of their total growth than has generally been thought necessary.

The relation of phytin and nonphytin phosphorus in developing corn grain was not fully disclosed by this study, perhaps because of insufficient fractionation data. From pollination through the fourth week thereafter, phosphorus was translocated into the kernels at such a rate as to increase both the phytin and nonphytin phosphorus. (Fig. 3). During the fifth, sixth, and seventh weeks, the relation of phytin to nonphytin phosphorus was determined in a general way. The rate of translocation of phosphorus into the grain decreased and a portion of the nonphytin phosphorus already present was synthesized into phytin. The nonphytin phosphorus already in the grain contributed 8, 83, and 40 % of that used for phytin formation during the three respective weeks. However, inasmuch as the nonphytin group contained soluble inorganic and labile organic phosphorus compounds, and since these were not fractionated, it is impossible to state what phosphorus compounds of the nonphytin group were synthesized into phytin. Whether phytin is formed from

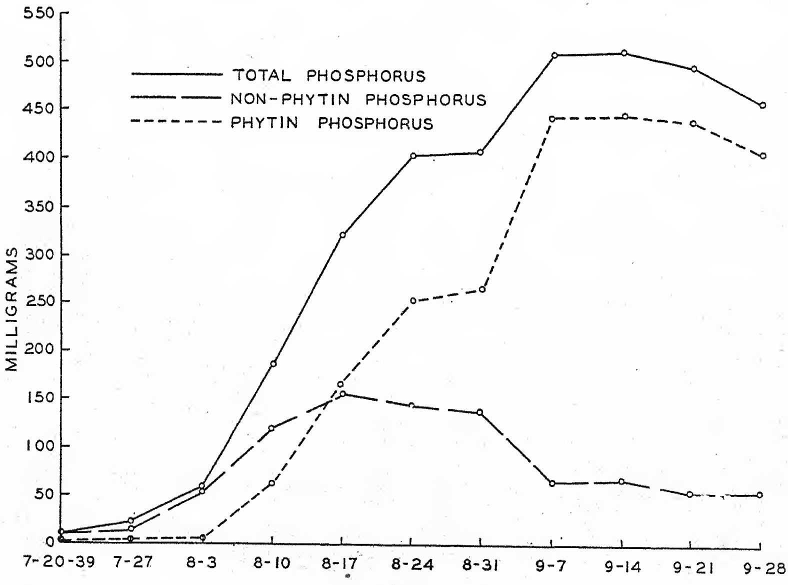


FIG. 3.—Cumulative milligrams of total phosphorus, nonphytin phosphorus, and phytin phosphorus in grain per ear at weekly intervals from pollination to maturity. July 20 values represent unpollinated ovules with associated tissues.

inorganic phosphorus and inosite, both of which exist free in immature corn fruits, or from the reaction of phospho-glycerol compounds, or from other phosphorus compounds still remains unknown It is probable that Posternak (19) has synthesized phytic acid *in vitro* from inosite and phosphoric acid (3, 4, 17, 18). This accomplishment, if a fact, would lend strength to the probability that soluble inorganic phosphates are utilized directly in phytin formation in the grains.

The loss of total and phytin phosphorus during the ninth and tenth weeks (Fig. 3) is believed to be due to the decrease found in dry weight of grain per ear (Table 1) for these two periods, accounted for by the chance harvesting of smaller ears than in the preceding week. At the earlier sampling periods, when the ears were rapidly enlarging, any slight sampling difference from one week to the next would have been masked by the rapid growth in size of ears. Had the dry weight of grain per ear remained constant during this late maturation period, no loss of either total or phytin phosphorus would have been observed.

Samples of silks were collected from the ears harvested before pollination and those harvested 1, 3, 5, and 7 days after pollination for the purpose of learning if phytin were present in the silks prior to or following pollination. The data are given in Table 4. Although each sample of silks analyzed contained phytin phosphorus, the percentage was low. The data seem to suggest a decrease in percentage of phytin phosphorus after pollination.

TABLE 4.—*Percentage phytin phosphorus present in corn silks.*

Interval after pollination	Phytin phosphorus, %	Av. % phytin phosphorus
Unpollinated	0.018 0.016	0.017
1 day	0.014 0.012	0.013
3 days	0.010 0.011	0.011
5 days	0.010 0.008	0.009
7 days	0.014 0.005	0.010

Five samples of corn pollen representing two varieties of corn ranged in phytin phosphorus content from 0.037 to 0.057% and averaged 0.043%, about 3½ times the concentration found in silks.

SUMMARY AND CONCLUSIONS

The progress of phytin synthesis in developing corn grain was followed during 10 weeks from just prior to pollination to complete maturity of the grain, at first at short intervals and at weekly intervals after the second week.

The time of initiation of phytin synthesis in the developing corn grain was not definitely established by this investigation. It was

shown, however, that phytin was present in the pistillate structure prior to fertilization, although the concentration was only 0.013%, or 2.1% of the total phosphorus. Phytin remained at this low level for 2 weeks after pollination in agreement with the previous findings of DeTurk, *et al.* (10).

The weekly gain in percentage of phytin phosphorus in the developing grain increased from the second to the fourth week, diminished somewhat during the fifth, and all but ceased during the sixth week. The synthesis then increased rapidly during the seventh week after which there was no further formation of phytin in the grain. The maximum rate of synthesis occurred during the seventh week following pollination. During this period 25.3 mgm of phytin phosphorus were formed daily per ear.

Formation of phytin during the first 4 weeks did not occur at the expense of nonphytin phosphorus stored in the immature fruits. This is indicated by the fact that translocation from the stalks and leaves or, in part, from the soil supplied as much as was needed for phytin formation. During the fifth, sixth, and seventh weeks nonphytin phosphorus already in the developing grain contributed part of that used in phytin synthesis. The amount was greatest in the seventh week when it provided 71 of the 177 mgms converted into phytin, leaving 106 mgm, or 60% of the total so used, to be supplied from leaves, stalk, and soil.

The evidence secured indicated that the cellular structure of the ovule is largely laid down during the first 4 weeks after pollination, with its full complement of nonlabile phosphorus. Active phytin synthesis accompanies this reaction during the third and fourth weeks and then becomes the dominant phosphorus reaction through the seventh week, at which time it is essentially completed. At full maturity, 10 weeks after pollination, phytin phosphorus amounted to 0.271%, or 88% of the total phosphorus.

In addition to finding phytin in unfertilized corn ovaries, it was also found to be present in corn pollen and silks. The percentage of phytin phosphorus in these materials was 0.043 and 0.017, respectively.

LITERATURE CITED

1. ADLER, L. Gewinnung von Phytase aus Maiz. Biochem. Ztschr., 75:319–338. 1916.
2. ANDERSON, R. J. Concerning the organic phosphorus compound of wheat bran and the hydrolysis of phytin. N. Y. State Agr. Exp. Sta. Tech. Bul. 40. 1915.
3. ———. Concerning inosite phosphoric acid. N. Y. State Agr. Exp. Sta. Tech. Bul. 79. 1920.
4. ———. Synthesis of phytic acid. Jour. Biol. Chem., 43:117–128. 1920.
5. ——— and KULP, W. L. Studies with corn pollen. N. Y. State Agr. Exp. Sta. Tech. Bul. 92. 1923.
6. AVERILL, H. P., and KING, C. G. The phytin content of foodstuffs. Jour. Amer. Chem. Soc., 48:724–728. 1926.
7. BAYLISS, W. M. The nature of enzyme action. London, New York. Ed. 5. 1925.
8. COLLATZ, F. A., and BAILEY, C. H. The activity of phytase as determined by the specific conductivity of phytin-phytase solutions. Jour. Ind. and Eng. Chem., 13:317–318. 1921.

9. DENNY, F. E. Eliminating the use of calcium carbonate in preparing plant tissue for analysis. Contr. Boyce Thompson Inst., 5:103–114. 1933.
10. DETURK, E. E., HOLBERT, J. R., and HOWK, B. W. Chemical transformations of phosphorus in the growing corn plant with results on two first-generation crosses. Jour. Agr. Res., 46:121–141. 1933.
11. DICKMAN, S. R., and BRAY, R. H. Colorimetric determination of phosphate. Ind. and Eng. Chem., Anal. Ed., 12:665-668. 1940.
12. EARLEY, E. B. Stoichiometric relations of iron and phosphorus in ferric phytate and a method for quantitative determination of phytin phosphorus. Ind. and Eng. Chem., An. Ed., 16:389–391. 1944.
13. HENRICI, M. Phosphormangel als Ursache von Storungen im Leben der Pflanze. Verhandle. Naturf. Gesell, Basel, 38:316–326. 1927.
14. KNOWLES, F., and WATKINS, J. E. The amount and distribution of some phosphorus and nitrogen compounds in wheat during growth. Jour. Agr. Sci., 22:755–766. 1932.
15. MCCAME, R. A., and WIDDOWSON, E. M. Phytin in human nutrition. Biochem. Jour., 29:2694–2699. 1935.
16. PLIMMER, R. H. A. The metabolism of organic phosphorus compounds. Their hydrolysis by enzymes. Biochem. Jour., 7:43–71. 1913.
17. POSTERNAK, S. The sythesis of inosityl phosphate and its identity with the organic phosphorus reserve substance of green plants. Compt. Rend., 169:138–140. 1919. (Chem. Abs., 13:2547. 1919.) Original not seen.
18. ————. The synthesis of inositohexa-phosphoric acid. Helvetica Chim. Acta., 4:150–165. 1921. (Chem. Abs., 15:1891. 1921.) Original not seen.
19. ————. Synthesis of inosite hexaphosphoric acid. Jour. Biol. Chem., 46:453–457. 1921.
20. RATHER, J. B. The determination of phytin phosphorus in plant products. Jour. Amer. Chem. Soc., 39:2506–2515. 1917.
21. SUZUKI, U., YOSHIMURA, K., and TAKAISHI, M. Über ein Enzym "Phytase" das "Anhydro-Oxymethylen Diphosphorsäure" Spaltet. Tokyo Chem. Soc., 27:1330–1342. 1906. (Chem. Abs., 1:1147–1148. 1907.) Original not seen.
22. WEBSTER, J. E. Phosphorus distribution in grains. Jour. Agr. Res., 37:123–125. 1928.
23. WRENSHALL, C. L., and DYER, W. J. Organic phosphorus in soils. II. The nature of the organic phosphorus compounds. Nucleic acid derivatives. Phytin. Soil Sci., 51:235–238. 1941.
24. YOUNG, Y. The determination of phytic acid. Biochem. Jour., 30:252–257. 1936.

THE USE OF ACIDIFYING MATERIALS ON CALCAREOUS SOILS[1]

D. W. Thorne[2]

SEVERAL reports of field and greenhouse experiments have led to a belief that plant nutrition and growth on calcareous soils are benefited by treating such soils with acidifying materials. This belief is based largely on the studies of McGeorge and co-workers (3, 4, 5)[3] in Arizona and on published pH preference values for plants.

In Utah, calcareous soils are widely distributed and chlorosis of horticultural crops, an associated nutritional deficiency disease resulting from unavailability of iron, is common. A number of field tests in which sulfur and manure composts were applied around chlorotic horticultural crops have given variable results. In only one or two instances has any marked recovery of plants growing on such treated soils been noted. In several field and greenhouse experiments, common field crops were grown on several of the most widely distributed soil types of northern and central Utah to which various acids and acid-forming materials had been added. These experiments are reported in this paper.

METHODS

In field experiments certain acidifying treatments were included with fertilizer tests. Greenhouse experiments utilized soils representing the surface foot of important soil types of northern and central Utah, and taken from fields of known cropping and fertilizer history. The variously treated soils were set out in the greenhouse in randomized blocks. Results obtained have been tested for significance by statistical analysis.

Chemical analysis of plants was made and reported on air-dry weight basis. Plant materials were digested with perchloric acid according to the method of Shelton and Harper (10), and the various elements were determined in aliquots of resulting solutions.

EXPERIMENTAL RESULTS

FIELD EXPERIMENTS

In 1929 a field experiment was begun north of Logan, Utah, on Millville loam, a soil that contains more than 40% calcium and magnesium carbonates. This experiment included 13 different soil treatments and a 6-year rotation of crops (9). One soil treatment included 250 pounds of sulfur per acre applied every year with farm manure and raw rock phosphate. Table 1 shows the mean annual yields of sugar beets, wheat, barley, alfalfa, and potatoes over a 12-year period (two complete rotations) for the sulfur-manure-rock phosphate combination, and for a few other comparative treatments.

In these tests no benefit was observed from the sulfur treatment. This lack of benefit was somewhat unexpected since Greaves and

---

[1]Contribution from the Agronomy Department, Utah Agricultural Experiment Station, Logan, Utah. Authorized for publication March 22, 1944. Received for publication April 4, 1944.

[2]Associate Agronomist.

[3]Figures in parenthesis refer to "Literature Cited," p. 828.

TABLE 1.—*Mean yields per acre per year of crops (12 years) with different fertilizer treatments on Millville loam.*

Fertilizer	Rate of application per acre, lbs.	Sugar beets, tons	Potatoes, bu.	Wheat, bu.	Barley, bu.	Alfalfa, tons
No fertilizer	—	10.64	288	37.6	63.1	6.83
Gypsum	330	10.24	281	37.5	64.4	6.86
Treble superphosphate (P)	350	15.31	292	39.6	68.2	7.66
Farm manure (M)	10 ton	18.29	328	53.6	77.7	7.85
M+1,000 lbs. rock phosphate (R)	—	17.79	344	51.5	73.8	7.74
M+R+250 lbs. sulfur	—	17.45	313	52.3	73.9	7.84
M+P	—	19.47	365	53.8	75.0	7.93

Gardner (1) reported in 1929 that the sulfur content of Millville loam soil in this area is only 252 pounds per acre foot and that this was a lower sulfur content than had been previously reported for any soil in the United States. It was also reported that the waters of Logan River, used for irrigation, contain only 7 pounds of sulfur per acre foot. From these data it was concluded that sulfur probably would be a limiting factor in plant growth on this soil. These results of Greaves and Gardner led, therefore, to the expectation that the addition of sulfur might overcome a nutritional deficiency as well as create acids through oxidation.

Another field experiment, which included some acidifying treatments, was begun in 1941 on Taylorsville silty clay loam, 10 miles southwest of Salt Lake City. This soil has a pH of about 8.0 at the moisture equivalent, and has a lime content of between 5 and 8% in the upper foot. Treatments were made broadcast and harrowed into the seedbed for spring wheat and sugar beets, but for potatoes the treatments were placed in bands about 3 inches deep to the sides of the rows. Results obtained with acidifying treatments and a few related materials are shown in Table 2. The experimental design included eight replications with a green manure crop and eight with-

TABLE 2.—*Mean yields per acre per year of Federation wheat, Russet potatoes, and sugar beets on Taylorsville silty clay loam as influenced by various treatments.*

Treatment	Wheat, bu.	Potatoes, bu.	Sugar beets, tons
No treatment	44.2	216.9	20.3
Treble superphosphate, 200 lbs. per acre	48.8	243.6†	22.4
Phosphoric acid, 162 lbs. per acre	47.1	243.1†	21.2
Farm manure, 10 tons per acre	50.1*	236.8*	20.3
Sulfur, 300 lbs. per acre	46.1	217.8	20.6
Manure+sulfur in compost	49.8*	226.0	21.3
Gypsum, 500 lbs. per acre	46.4	220.4	18.4

*Mean yield is greater than the mean of untreated plots beyond the 5% level of significance.
†Mean yield is greater than the mean of untreated plots beyond the 1% level of significance.

out a green manure crop. This was equivalent to 16 replications for the fertilizer treatments.

The results indicate no beneficial effect from acidifying materials. Phosphoric acid did not induce greater yields than similar amounts of phosphorus applied as concentrated superphosphate. Each year the sulfur and manure compost was mixed 3 months before being added to the soil. It had pH values between 3.0 and 4.0 at the time of application. But the composted sulfur was no more effective in increasing yields than sulfur alone and did not induce greater yields than untreated manure which had a pH of nearly 9.0.

TABLE 3.—*Mean yields of three crops of alfalfa and of barley grown in the greenhouse on three soils as influenced by acidifying materials, averages of two replications.*

Treatment	Alfalfa yields, grams			Treatment means, grams	Barley yields, grams			Treatment means, grams
	W.c.l.*	S.L.l.*	M.l.*		W.c.l.	S.L.l.	M.l.	
None	20.2	11.2	11.9	14.4	11.1	25.6	14.0	16.9
Sulfur A†	14.6	13.5	13.2	13.8	10.6	17.1	17.4	15.0
Sulfur B	16.6	11.4	12.3	13.4	15.1	15.1	13.3	14.5
H_2SO_4 A	14.1	11.7	13.4	13.1	10.7	31.8	10.1	17.5
H_2SO_4 B	13.1	10.4	13.2	12.2	11.6	18.4	10.5	13.5
H_3PO_4 A	16.9	14.6	12.9	14.8	10.2	17.1	14.2	13.8
H_3PO_4 B	19.2	16.4	14.4	16.7	16.4	26.4	11.0	17.9
H_2SO_4, pH 3, water	9.6	7.4	10.6	9.2	12.5	33.7	16.9	21.0
H_3PO_4, pH 3, water	14.5	10.4	13.5	12.8	11.8	20.0	20.6	17.5
Manure and sulfur A	20.0	14.0	15.2	16.4	11.8	24.1	15.6	17.2
Manure+sulfur B	22.1	14.9	14.7	17.2	15.6	14.9	12.5	14.3
Manure	24.2	15.6	11.6	17.2	16.6	25.5	16.1	19.4
Treble superphosphate (P)	19.7	15.3	14.6	16.5	13.7	24.4	13.6	17.2
Sulfur A+P	20.7	14.1	12.8	15.9	14.5	25.5	16.0	18.7
Sulfur B+P	16.6	13.4	15.5	15.2	10.5	17.8	14.8	14.4
H_2SO_4 A+P	16.3	14.2	13.3	14.6	14.6	16.1	15.1	15.3
H_2SO_4 B+P	13.6	12.9	13.2	13.3	13.8	14.3	12.4	13.5
H_3PO_4 A+P	20.3	15.7	12.9	16.3	15.7	21.7	13.7	17.0
H_3PO_4 B+P	17.4	16.3	12.9	15.5	13.4	18.5	12.3	14.7
H_2SO_4 in water, pH 3.0+P	13.0	10.1	11.6	11.6	15.0	19.6	12.7	15.8
H_3PO_4 in water, pH 3.0+P	12.1	11.9	10.6	11.5	14.3	27.2	14.4	18.6
Manure + sulfur A + P	19.1	14.6	17.5	17.1	13.3	21.2	13.3	15.9
Manure + sulfur B + P	22.3	13.7	16.2	17.4	14.5	16.1	17.7	16.1
Manure + P	19.7	15.6	12.8	16.0	18.3	21.2	15.9	18.5
Gypsum A	17.6	12.4	13.7	14.6	16.1	21.0	14.2	17.1
Gypsum B	15.8	11.7	11.7	13.1	10.6	28.1	11.5	16.7

*W.c.l. = Woodrow clay loam; S.L.l. = Salt Lake loam; M.l. = Millville loam.

†Sulfur A, 800 lbs. per acre; sulfur B, 1,600 lbs. per acre. Other A and B treatments based on acidity equal to the potential acidity of the sulfur treatments.

GREENHOUSE EXPERIMENTS

In the first greenhouse test 26 treatments were made on three soils. Woodrow clay loam, 30% lime; Salt Lake loam, 5% lime; and Millville loam, 44% lime. Woodrow clay loam also contained almost 4,000 p.p.m. of soluble salts which were predominantly sodium sulfate. Salt Lake loam contained 2,600 p.p.m. of soluble salts which were principally sodium chloride but also included 15 p.p.m. of sodium carbonate. The soils were placed in 2-gallon pots and treatments shown in Table 3 were mixed with the upper 3 inches of soil. The rates of acid treatments were equivalent to the potential acidity of either (A) 800, or (B) 1,600 pounds of sulfur per acre. Manure was added at a rate of 10 tons per acre, and treble superphosphate at 200 pounds per acre. Alfalfa was planted and three crops harvested. The alfalfa was followed by a crop of barley, and this in turn by corn. The mean yields for the various soils and treatments are shown in Table 3 for alfalfa and barley. The corn yields were not significantly influenced by soil treatment and are not shown.

A statistical analysis of the data summarized in Table 3 showed that the variances owing to soils, treatments, and the treatment × soil interaction were highly significant for both crops, but in no case were the yields significantly increased on a statistical basis by the acidifying treatments. Irrigation water acidified to pH 3.0 by sulfuric acid decreased the yields of alfalfa. Manure or phosphate alone gave as good results as when combined with sulfur or acids, and phosphoric acid was not superior to treble superphosphate. There was no significant difference between mean yields of barley as a result of the various treatments.

In a second series of greenhouse tests Wasatch loam was used in addition to the three soils included in the previous experiment. Wasatch loam is largely derived from granitic materials and is usually considered noncalcareous, although the sample employed had a small amount of lime in the sand fraction. The soils were placed in 1-gallon pots and banded treatments placed in three bands 1 inch wide, across the pots, 2 inches apart and 2 inches below the soil surface. Treatments were replicated three times. Dried manure was added at a rate of 1 ton per acre and sulfuric acid at 1,000 pounds per acre. The manure and acid were thoroughly mixed before placing in the soil. Irrigation waters were treated with sulfuric acid to bring to the desired pH. These waters were used for all irrigations of soils designated for acidified waters. Stone tomatoes were planted and thinned to 10 plants per pot. They were harvested after 8 weeks' growth. Yields obtained and their statistical analysis and some of the soil characteristics are shown in Table 4.

The tomato plants produced on Wasatch loam, Millville loam, and Salt Lake loam were analyzed for iron, manganese, and calcium. Table 5 shows the mean values for iron on the basis of p.p.m. of iron in the plants and total iron uptake by the 10 plants in each pot. Data and statistical analysis for manganese and calcium content of the tomatoes are shown in Table 6.

The treatment mean data indicate that, on an average for all soils, manure alone increased the concentration of iron and manganese

TABLE 4.—*Yield of tomatoes as influenced by acidifying materials and some characteristics of the soils used.*

Soil analysis and treatment	Wasatch loam	Wood-row clay loam	Mill-ville loam	Salt Lake loam	Treat-ment means
		Soil Analysis			
pH soil paste	7.8	8.1	7.85	8.5	—
pH 1-10 dilution of soil	9.1	9.55	9.15	10.1	—
$CaCO_3$, %	1.8	30.2	44.1	5.4	—
Water-soluble calcium, p.p.m.	75.0	210.0	223.0	71.0	—
Soluble salts, p.p.m.	375.0	2,600.0	450.0	3,950.0	—
		Plant Yields*			
None	12.7	14.3	27.7	10.7	17.0
Irrigation water, pH 3.0	11.1	15.6	27.6	22.8	20.5
Irrigation water, pH 5.0	11.2	17.0	23.4	21.2	18.6
Dried manure in bands	10.8	13.5	21.1	21.0	17.6
Manure-H_2SO_4 in bands	16.7	13.6	26.1	24.6	23.5
Manure–treble superphosphate in bands	16.2	16.9	27.7	19.4	21.1
Manure–H_2SO_4-treble superphosphate in bands	17.2	17.0	30.0	18.9	22.0
Soil means	13.7	15.4	26.2	19.8	20.0

*Grams per pot, dry-weight basis; means of three replications.

Analysis of variance

Source of variation	D.F.	M.S.
Treatment	6	5.82
Soils	2	138.45**
Blocks	2	3.75
Soil × treatment	12	6.27*
Error	40	2.79

*Significant.
**Highly significant.

in the plants. Sulfuric acid added to the manure tended to increase further the content of iron but did not increase the manganese. Treble superphosphate treatments both with and without acid decreased the iron and manganese contents of the tomatoes. Irrigation of the soils with water acidified with sulfuric acid had no pronounced effect on any of the factors studied. The treatment means are not reliable indicators of the value of acidifying materials, however, because the treatment variances for yield, total iron, and percentage calcium were not significant. Furthermore, the treatment × soil interactions were highly significant for p.p.m. of iron and percentage calcium and significant for yield and manganese content. The significance of these interactions implies that the treatment effects varied among the three soils, and opens the question whether the acidifying treatments gave results different from other treatments on each of the soils, and particularly whether the treatments reacted differently on the noncalcareous Wasatch loam than on the two calcareous soils. For the banded applications this question is best answered by

comparing for each soil the sum of the data for the manure and manure + phosphate treatments as against those for the sum of manure + sulfuric acid and manure + phosphate + acid treatments according to statistical methods for segregating the variance for single degrees of freedom.

TABLE 5.—*Iron content of tomato plants as influenced by acidifying materials, mean values for three replications.*

Treatment	Iron content, p.p.m.				Total iron uptake, mgms per 10 plants			
	W.l.*	S.L.l.*	M.l.*	Treatment means	W.l.	S.L.l.	M.l.	Treatment means
No treatment	482	304	322	369	2.05	1.20	2.89	2.08
Water, pH 3	355	311	343	336	1.29	2.57	3.23	2.37
Water, pH 5	404	332	284	340	1.49	2.36	2.92	2.26
Manure	477	421	379	426	1.73	2.97	2.67	2.46
Manure + H_2SO_4	686	523	274	494	3.85	4.09	2.36	3.45
Manure + P	464	281	276	340	2.35	1.81	2.52	2.23
Manure + P + H_2SO_4	385	416	290	364	2.26	2.56	3.04	2.62
Soil means	465	370	310	381	2.15	2.51	2.80	2.50

*W.l. = Wasatch loam soil; S.L.l. = Salt Lake loam soil; M.l. = Millville loam soil.

Analysis of variance

Source of variation	D.F.	Mean square	
		Iron content	Total iron uptake
Treatments	6	26,081*	1.89
Soils	2	106,180**	2.25
Blocks	2	35,095	0.86
Soil × treatment	12	24,664**	1.53
Error	40	8,898	1.27

*Significant.
**Highly significant.

Such comparisons indicate no distinctive effect of the acidifying treatments on the noncalcareous Wasatch loam as compared with their influence on the two calcareous soils. The banded sulfuric acid combinations were less effective in increasing tomato yields on Salt Lake loam than on the other two soils. Likewise, the banded acid treatments decreased the iron and calcium contents of the plants on the highly calcareous Millville loam, but increased the iron and calcium contents of plants on the other two soils. The manganese content of the tomatoes was decreased by the acid treatments on Wasatch and Millville loam soils. Only on Salt Lake loam, which contains a small amount of sodium carbonate, were the results consistently favorable to the use of acid treatments, and even then only in the case of p.p.m. of iron in plants was the increase resulting from the acid treatments great enough to be statistically significant.

Statistical analysis of the data for total iron showed that none of the factors studied affected the total uptake of iron to a significant degree. This lack of effect of treatments or soils on total iron uptake, as compared with the observed differences for iron concentration in the plants, appears to result from a difference in the effects of treatment upon yield and iron content of plants and from a relative increase in variation in the data from multiplication of iron content of plants times yield.

TABLE 6.—*The manganese and calcium content of tomato plants as influenced by acidifying materials, mean values for three replications.*

Soil treatment	Manganese content, p.p.m.				Calcium content, %			
	W.l.*	S.L.l.*	M.l.*	Treatment means	W.l.	S.L.l.	M.l.	Treatment means
No treatment	178	159	221	186	1.99	2.91	2.24	2.38
Water, pH 3	156	154	242	184	1.62	2.99	2.51	2.37
Water, pH 5	154	187	240	194	2.24	1.68	2.52	2.15
Manure	258	174	249	227	1.95	3.14	2.76	2.62
Manure+H_2SO_4	128	183	213	175	2.22	3.16	2.30	2.56
Manure+P	167	121	168	152	2.16	2.87	2.32	2.45
Manure+P+H_2SO_4	164	128	136	143	2.34	3.18	2.08	2.53
Soil means	172	140	210		2.07	2.85	2.39	

*W.l. = Wasatch loam; S.L.l. = Salt Lake loam; M.l. = Millville loam.

Analysis of variance

Source of variation	D.F.	Mean square	
		Manganese	Calcium
Treatments	6	7,611**	0.17
Soils	2	13,068**	2.81**
Blocks	2	2,768	0.05
Soils × treatments	12	3,161*	0.39**
Error	40	1,256	0.099

*Significant.
**Highly significant.

The relationships between mineral absorption and soil characteristics are not consistent. Mean iron content of the plants varied inversely with lime content of the soils. With manganese, greatest concentration occurred in plants grown on the highly calcareous Millville loam and lowest concentration in those grown on the intermediate lime soil, Salt Lake loam. Order of calcium uptake by the plants shows no apparent relationship to iron or manganese uptake nor to lime content of the soils.

After harvesting the tomato plants, alfalfa was planted without disturbing the banded treatments. The second crop of alfalfa was analyzed for iron, manganese, calcium, and phosphorus. Only phosphate content of the plants was appreciably affected by the treat-

ments. The mean yields for the two crops of alfalfa and the mean analytical values for phosphate are given in Table 7. The other analyses are not shown. The variance analysis of both yield and phosphate content showed significant differences between soils and between treatments. The treatment × soil interaction was significant for phosphate content but not significant for yield. The principal source of variance between treatments resulted from a decrease in yield from the use of acidified irrigation waters, and an increase in phosphate content from the combined manure, phosphate, and acid treatment. The banded applications had no appreciable influence on yield and the acidified irrigation water induced an increase in phosphate content of only the alfalfa growing on Millville loam.

TABLE 7.—*Mean yields of two crops of alfalfa and the percentage of phosphorus in second crop alfalfa as influenced by acidifying materials, mean values for three replications.*

Treatment	Yield, grams per pot				Phosphorus content, %			
	W.l.*	S.L.l.*	M.l.*	Treatment means	W.l.	S.L.l.	M.l.	Treatment means
No treatment	11.03	7.62	11.75	10.13	0.18	0.23	0.24	0.22
Water, pH 3	8.68	8.22	9.12	8.67	0.17	0.25	0.30	0.24
Water, pH 4	8.03	8.67	10.28	8.99	—	—	—	—
Water, pH 5	8.00	7.60	9.57	8.39	0.17	0.22	0.27	0.22
Water, pH 6	8.00	7.43	9.12	8.18	—	—	—	—
Manure	11.08	9.93	12.93	11.32	0.19	0.21	0.26	0.22
Manure+H_2SO_4	10.45	8.90	11.07	10.14	0.20	0.20	0.24	0.21
Manure+P	11.13	10.10	11.43	10.89	0.22	0.23	0.23	0.23
Manure+P+H_2SO_4	10.18	8.27	13.00	10.48	0.24	0.26	0.28	0.26

*W.l. = Wasatch loam; S.L.l. = Salt Lake loam; M.l. = Millville loam.

On the soils treated with acidified irrigation waters, pH was determined by removing the upper inch of soil and pressing a glass electrode into the moist soil below. Results obtained are shown in Table 8. All acidified irrigation treatments, except the pH 6 water, resulted in small, though statistically significant, decreases in the pH values of the three soils. In the soils irrigated with acidified waters analysis with a conductivity bridge did not indicate a sufficient increase in soluble salts to account for the decreased yields.

TABLE 8.—*Mean pH values of three soils as influenced by acidified irrigation water.*

Treatment	Wasatch loam	Salt Lake loam	Millville loam	Treatment means
No treatment	7.90	8.63	8.33	8.29
Water, pH 3	7.60	8.12	7.95	7.89
Water, pH 4	7.75	8.25	7.98	7.99
Water, pH 5	7.68	8.33	8.15	8.05
Water, pH 6	7.90	8.40	8.25	8.18

Several tumbler experiments were conducted with various soils and acidifying materials to obtain information which might aid in interpreting the influence of such acidifying materials. Results with pH determinations were highly variable and frequently showed no consistent pH changes from applications of such acidifying materials as aluminum sulfate, ferrous sulfate, and sulfuric acid in amounts equivalent to the potential acidity of 10 tons of sulfur per acre. When applied in bands or pockets, the zone of influence was so limited as to make representative analysis difficult.

Tumbler experiments were also conducted with nine different Utah soils, using sulfur mixed with the soils, and sulfur placed in bands and pockets. In all soils studied sulfur was readily oxidized when mixed with the soils, but was only slowly attacked when placed in concentrated bands or pockets. This substantiated field observations. Sulfur placed in bands in the spring by potato rows was largely unchanged in the late fall.

A tumbler experiment was conducted to determine the chemical effects of manure and various acidifying materials on some chemical properties of four calcareous soils, Woodrow clay loam, Trenton clay, Millville loam, and Salt Lake loam. Treatments with acidifying materials were made at rates equivalent to 800 and 1,600 pounds of sulfur and the manure at 10 tons per 2,000,000 pounds of soil. The treatments were mixed with 100-gram portions of the soil and placed in glass tumblers. They were maintained at room temperature and optimum moisture content. At intervals of 4, 8, and 16 weeks from the treatment date duplicate tumblers of treated soil were removed and analyzed for pH, water-soluble calcium, and phosphorus soluble in a pH 5 acetate buffered solution. No definite differences were observed over the period for soluble phosphorus. The results for pH and soluble calcium were similar for all soils.

Figs. 1 and 2 show the trends for pH and soluble calcium in Salt Lake loam treated with acidifying materials equivalent to 1,600 pounds of sulfur. The results are helpful in interpreting the effects of the various treatments. In these and other studies the water-soluble calcium seems to be a better indicator of acidifying effects than pH. Thus, the calcium analyses indicate a gradual sulfur oxidation over the period of the experiment, but there was a gradual increase in soil pH after the fourth week. Phosphoric acid, however, decreased the pH but tied up the calcium. Manure did not appreciably alter either pH or calcium solubility.

DISCUSSION

In many western states the use of sulfur and other acidifying agents as soil amendments is being promoted by certain commercial agencies. Insufficient data are available as yet, however, to indicate whether any value may accrue from their use on normal calcareous soils. The Anaconda Sales Company[4] reports that in several trials better results have been obtained from applying phosphoric acid in irrigation water than from applying concentrated superphosphate

[4]Private correspondence with R. A. Jones, 1941.

to the soil. Our results with several Utah soils showed no superiority of the acid over concentrated superphosphate on the basis of equal phosphorus applications (Tables 2 and 3). Unpublished observations by research and extension workers in Idaho[5] and California, as well as in Utah, also indicate that responses from sulfur applications to soil in these states are spotted. Beneficial results appear to occur on non-calcareous soils almost as frequently as on calcareous soils.

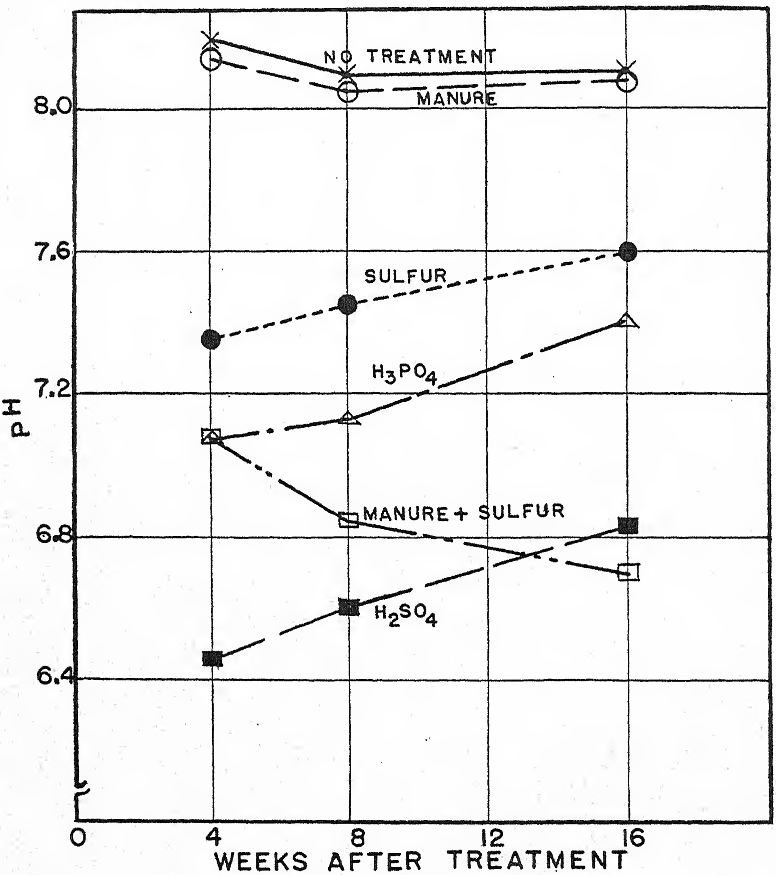


FIG. 1.—The pH of Salt Lake loam as influenced by various treatments. Acid treatments were equivalent to the potential acidity of 1,600 pounds of sulfur per acre. Manure was applied at the rate of 10 tons per acre.

Negoroshkov (8) applied acids to a chernozem soil to determine effects on yield. The acids generally decreased the yield of oats, which was the first crop after treatment, but some of the acids had a beneficial residual effect on the second crop, wheat. Oxalic and hydro-

[5]Private correspondence with H. W. E. Larson, 1940.

chloric acids were injurious in all cases. Most beneficial results were from sulfuric acid and sodium hydrogen sulfite treatments. In some cases wheat yields were increased as much as 40% following the acid treatments. A detailed report of these experiments was not available to the author of this paper so no pertinent conclusions can be drawn.

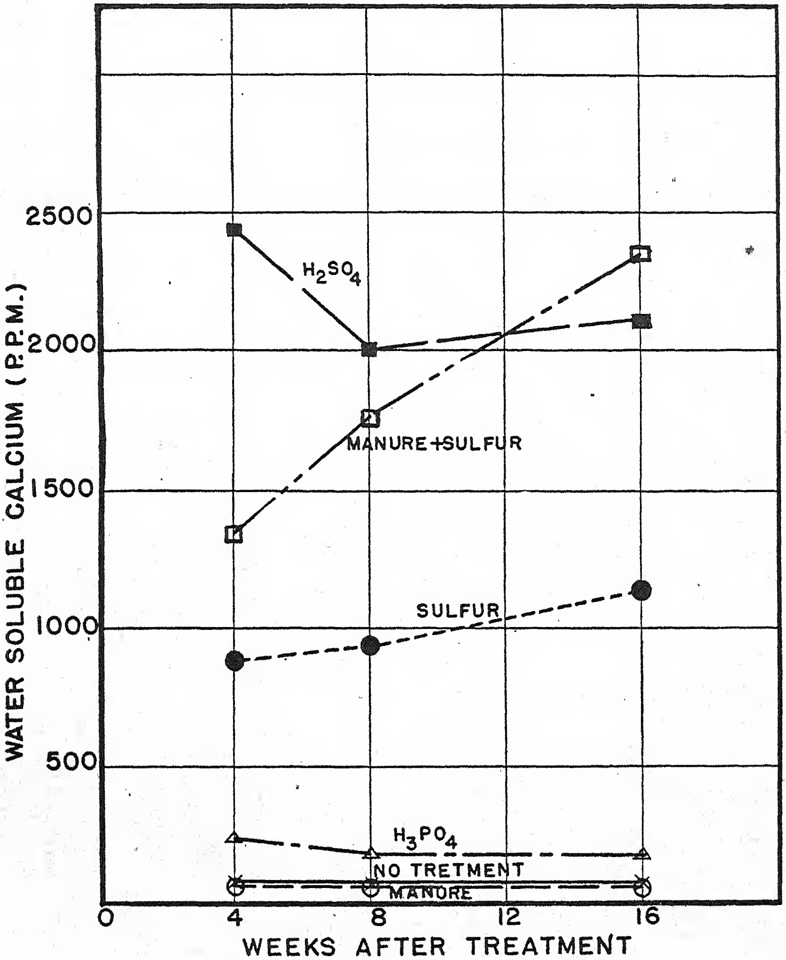


FIG. 2.—Water-soluble calcium in Salt Lake loam as influenced by various treatments. Acid treatments were equivalent to the potential acidity of 1,600 pounds of sulfur per acre. Manure was applied at the rate of 10 tons per acre.

McGeorge (5, 6) concluded from his studies that acidifying materials increase the availability of plant nutrients in calcareous soils. While some of the data presented by McGeorge could be interpreted as indicating an increased absorption of iron and manganese, other data are reported which could be similarly interpreted

as indicating that acidulation decreased absorption of these elements by several crops. The results appear even less indicative of any increased phosphorus or nitrogen absorption by the plants as a result of acidulation than was observed for the minor elements. Data most indicative of benefits from acidifying treatments were obtained with crops commonly grown during the winter months in Arizona. It has been suggested that seasonal differences may account for any discrepancy between results in Utah and Arizona.[6]

The value of sulfur as a soil amendment on calcareous soils is further placed in question by the studies of Hinkle and Staten (2) in New Mexico. In their tests various types of sulfur added to a heavy, plastic, calcareous soil failed to increase the yield of cotton sufficiently to pay for the cost of the sulfur.

The experiments reported here indicate that little benefit accrues from the addition of acidifying materials to soils. In the broadcast treatments, as reported in Tables 1 and 2, rates of application of acidifying materials were only large enough to react with a small fraction of the soil lime. Even in the banded applications the zone of influence was so limited that it could not be detected in pH determinations. Where relatively large treatments of sulfur and sulfuric acid were made there was a considerable increase in soluble salts which might have some harmful effects under greenhouse conditions. If the maximum values for soluble calcium, as shown in Fig. 2, are interpreted in terms of calcium sulfate, the concentration would amount to 0.8% (only a fraction of which could be dissolved in the soil solution). An injurious concentration of salts might result in soils kept in greenhouse pots and treated with acidifying materials. However, in the well-drained soils employed in field experiments, frequent leaching with irrigation water would prevent any harmful accumulation of salts.

Some basis for benefit might accrue from the production of carbon dioxide following acidifying treatments. In the case of acids, however, the period of evolution would be so short that no appreciable benefit in terms of altered soil conditions could be expected. There is also the possibility of increased availability of some plant nutrients within limited acidified zones. Soil analyses indicate a definite increase in soluble calcium (Fig. 2), but data for soluble phosphorus are inconclusive. In the greenhouse experiments reported, the mineral contents of plants showed no consistent relation to acidifying treatments. While there was a tendency for the total uptake of iron and calcium to increase from the acid-treated soils, the differences were not significant. Furthermore, the noncalcareous Wasatch loam responded in much the same manner to the treatments as did the calcareous soils. The increase in the phosphorus content of alfalfa (Table 7) indicates that the acidified manure treatment might have retarded phosphate reversion in three soils. This point has not been sufficiently studied, however, to show how general such a benefit might be.

The literature cited and the results of the present investigation indicate that insufficient evidence has been accumulated to justify

[6]Private correspondence with W. T. McGeorge, 1944.

any unqualified acceptance of the use of acidifying treatments on calcareous soils. No benefits such as increased plant growth or increased uptake of minor elements have been established.

SUMMARY

1. Field, greenhouse, and laboratory experiments were conducted to determine the influence of acidifying treatments on yield and chemical composition of plants growing on various calcareous soils.

2. In a field experiment on Taylorsville silty clay loam, which contains 5 to 8% lime, the yields of wheat, potatoes, and sugar beets were not increased by sulfur, sulfur and manure compost, or phosphoric acid over the yields of comparable nonacidified treatments. In a 12-year study on Millville loam, which contains over 40% lime, sulfur and rock phosphate added to manure did not result in better yields than manure treatments alone.

3. In greenhouse studies the yields of alfalfa, barley, and corn growing on three different calcareous soils were not significantly increased by acidifying treatments, including two rates of sulfur, sulfuric acid, and phosphoric acid, over yields obtained from comparable treatments that were not acidifying. Irrigation water acidified to pH 3.0 by sulfuric acid decreased the yield of alfalfa.

4. In a greenhouse test with two calcareous soils and one noncalcareous soil, water acidified to pH 3.0 and to pH 5.0 with sulfuric acid had no significant effect on the yield or mineral content of tomato plants, but the treatments decreased the yield of alfalfa. Results on the noncalcareous soil were not appreciably different from those on the calcareous soils.

In this same experiment banded applications of sulfuric acid, dried manure, and treble superphosphate in various combinations showed no distinctive effects on calcareous soil compared with their effects on the noncalcareous soil in regard to yield, or to iron, manganese, or calcium contents of tomato plants. The treatment means for all soils indicate that manure bands alone increased the concentration of iron in the plants. Sulfuric acid added to the manure further increased the content of iron but did not increase the manganese. Treble superphosphate decreased the iron and manganese contents. But the specific effects varied from soil to soil and indicate no distinctive benefits from the acid treatments on calcareous soils compared with a noncalcareous soil.

5. Alfalfa following the tomatoes was significantly decreased in yield by acidified irrigation waters. Phosphate content of alfalfa was significantly increased by the banded treatment combination of manure, sulfuric acid, and concentrated superphosphate. Other treatment effects were not significant.

6. Irrigation with waters acidified to pH 3.0, 4.0, 5.0, and 6.0 with sulfuric acid decreased the pH of three soils somewhat in proportion to the degree of acidity of the water used, but in no case was the pH of calcareous soils lowered below 7.0.

7. Water-soluble calcium determinations gave more consistent values in relation to the effects of sulfur and sulfuric acid treatments

than did pH. Phosphoric acid decreased the pH of some soils but did not increase the calcium solubility. Farm manure treatments did not result in changes in either pH or soluble calcium in soils. The acidifying treatments showed no relationship to phosphorus soluble in a pH 5 acetate buffered solution.

8. A consideration of the results of this study and other reported investigations on the use of acidifying materials on calcareous soils indicates that there is insufficient evidence to date to warrant any widespread recommendation of such treatments for benefiting plant nutrition and growth. The value of acidifying agents in preventing phosphate reversion in calcareous soils has not been studied extensively enough to warrant conclusions.

LITERATURE CITED

1. GREAVES, J. E., and GARDNER, W. Is sulfur a limiting factor of crop production in some Utah soils? Soil Sci., 27:445–457. 1929.
2. HINKLE, D. A., and STATEN, GLEN. Fertilizer experiments with Acala cotton on irrigated soils. N. M. Agr. Exp. Sta. Bul. 280. 1941.
3. MCGEORGE, W. T. Acidulated fertilizers for alkaline soils. Calif. Citrog., 21:368. 1936.
4. ————. Some problems connected with the fertilization of alkali soils. Calif. Citrog., 24:389. 1939.
5. ————. Acidulated fertilizers for Arizona soils. Ariz. Agr. Exp. Sta. Tech. Bul. 101. 1943.
6. ————, and FRAZIER, W. A. Sulfur placement in the fertilization of alkaline soils. Soil Sci. Soc. Amer. Proc., 4:288–289. 1939.
7. ————, and GREENE, R. A. Oxidation of sulfur in Arizona soils and its effect on soil properties. Ariz. Agr. Exp. Sta. Tech. Bul. 59. 1935.
8. NEGOROSHKOV, A. L. The use of acids as a factor in increasing crop yields. Uchenye Zapiski Kazan Gosudarst. Univ., 97:107–150. Chem. Abst., 33:7459. 1937.
9. PITTMAN, D. W., and THORNE, D. W. Fertilizers for Utah soils. Utah Agr. Exp. Sta. Cir. 116. 1941.
10. SHELTON, W. R., and HARPER, H. J. A rapid method for the determination of total phosphorus in soil and plant material. Iowa State College Jour. Sci., 15:403–413. 1941.

INFLUENCE OF CERTAIN SOIL AMENDMENTS ON THE YIELD OF COTTON AFFECTED BY THE FUSARIUM-HETERODERA COMPLEX[1]

J. A. PINCKARD AND O. A. LEONARD[2]

COTTON wilt is a complex disease causing serious annual losses throughout the southeastern states. The disease may be caused by one or more parasitic microorganisms and aggravated by soil and environmental conditions. Although *Fusarium vasinfectum* Atk. is considered to be the primary cause of cotton wilt, the disease is usually complicated by the presence of root-knot nematodes, *Heterodera marioni* (Cornu) Goodey, which are present in many of the sandy soils of the cotton belt. Furthermore, potash hunger, and drouth, as well as several poorly understood soil-borne pathogens are almost invariably superimposed upon the wilt problem under field conditions.

Methods for the control of cotton wilt have been under investigation in the South for the past half century. This work has resulted in the development of resistant varieties and the use of potassium-bearing fertilizers where need is indicated. These methods of control have failed to prevent the disease in certain fields in Mississippi, and elsewhere. It seemed rather obvious that by combining fusarium wilt resistance with soil amendments a condition might be established in the soil wherein *F. vasinfectum* could be partially held in check by host resistance and the several complicating soil factors and pathogens blocked by the changed soil conditions. It was realized, of course, that success would be relative and dependent upon many unknown factors which could not be investigated at the moment. This empirical approach to the problem was unfortunately unavoidable.

Because several resistant varieties were already available and little was known of the effects of soil amendments upon the wilt problem as a whole, the latter studies have received major consideration, first under the leadership of the late H. C. McNamara and the late L. E. Miles, and more recently by the present writers.

The purpose of this paper is to report further progress of these investigations, some results of which have been announced (8).[3]

---

[1]Contribution from the Departments of Plant Pathology and Agricultural Engineering, Mississippi Agricultural Experiment Station, State College, Miss., cooperating with the Division of Cotton and Other Fiber Crops and Diseases, Bureau of Plant Industry, Soils, and Agricultural Engineering, Agricultural Research Administration, U. S. Dept. of Agriculture. Journal paper No. 74 (n.s.) of the Mississippi Agricultural Experiment Station. Received for publication May 22, 1944.

[2]Plant Pathologist, Mississippi Agricultural Experiment Station, and Agent, Division of Cotton and Other Fiber Crops and Diseases, U. S. Dept. of Agriculture, and Plant Physiologist, Mississippi Agricultural Experiment Station, respectively.

[3]Figures in parenthesis refer to "Literature Cited", p. 842.

MATERIALS AND METHODS

A study of the effect of several soil amendments on the yield of cotton as affected by certain soil-borne diseases has been under way in Mississippi at two branch stations for several years. Following is a brief resume of the field conditions and methods under which these studies were conducted.

RUSTON SANDY LOAM, POPLARVILLE, MISS.

Field plots on Ruston sandy loam near Poplarville, Miss., were established in the spring of 1933 for the purpose of comparing rates of 6–8–4 commercial fertilizer and stable manure on the yield of seed cotton. The treated plots consisted of five rows, each 53 feet 3 inches long, replicated four times in a randomized arrangement. The untreated plots were replicated eight times. The several soil amendments used were weighed and distributed under the rows in the bottom of deep furrows 2 or 3 days before seeding. A 6–8–4 commercial fertilizer was used at rates per acre of 200, 400, 600, 800, 1,000, and 1,200 pounds. Stable manure was used at rates of 2, 4, 6, 8, 10, and 12 tons per acre. Unfortunately, no information is available on the analyses of the stable manure or the sources of materials used in the commercial fertilizers. The yield in pounds of seed cotton per acre was computed from the three middle rows of each plot for the years 1933 to 1940, inclusive. Following harvest the entire field was seeded to vetch.

Both fusarium wilt and root-knot were known to be present in these plots in 1933, though no detailed data were available on their distribution within the experimental area until the fall of 1942. In the latter year, during harvest, 200 plants were selected at random in each treatment and were examined for the presence of *Fusarium vasinfectum* and *Heterodera marioni*. Data were taken on numbers of plants showing symptoms of wilt. Both external symptoms and blackened vascular systems were considered as evidence of fusarium wilt infection. The roots of these plants were examined and classified according to the numbers and size of knots present. An arbitrary classification was selected as follows: None, 0; moderate, 1; serious, 2; and severe, 3. Fig. 1 shows the severe type of root injury on selected plants from an untreated check plot of Sarpy fine Sandy loam at Stoneville. These symptoms were similar to those on Ruston sandy loam near Poplarville. Data were also taken on the height of the plants and diameter of main stem at the ground line. The variety of cotton used in these experiments was a local selection of Delta and Pine Land designated as 26–5C-6A. It was used throughout the experiments at Poplarville.

SARPY FINE SANDY LOAM, STONEVILLE, MISS.[4]

The field plots on this soil were established in the fall of 1939 at the Delta Branch Experiment Station near Stoneville, Miss. The plots consisted of five rows, each 60 feet long, in a randomized arrangement. The treated plots were replicated four times and the untreated plots eight times. The soil amendments used in these experiments were applied during January or February. Table 1 shows the arrangement of plots, materials used, and methods of application.

Stable manure of unknown composition but consisting principally of mule dung from the barns was used at rates of 4 and 8 tons per acre, both in the furrows and as a top dressing. Cyanamid at rates of 30, 60, and 90 pounds of nitrogen per acre was buried in the furrows. Dry sagrain, *Sorghum vulgare*, enriched with ammonium sulfate equivalent to 30 pounds of nitrogen per acre was was also buried in the furrows. The sagrain was grown on a nearby field and when needed the standing stalks with attached leaves were cut and the furrows packed full by tramping. Cotton stalks from surrounding plots were collected in a similar manner and the furrows were filled and tramped. Spoiled alfalfa hay was similarly buried in the furrows. Fig. 2 shows the amount used in a 10-inch furrow. Unfortunately, no records were kept on the weights or chemical composition of sagrain, cotton stalks, or alfalfa hay used in this work. However, 10-inch furrows were completely filled and packed and it is probable that at least 10 to 20 tons of field material per acre were used.

---

[4]The writers wish to express their appreciation for the help received in this work by Mr. J. H. Faulkner and others of the Stoneville Branch Station.

An attempt was made in the fall of 1939 and again in 1942 to determine the distribution of both *Heterodera marioni* and *Fusarium vasinfectum* in these field plots. After harvest, but before frost had killed the leaves, maps were made showing the location of plants suspected of being diseased by each of the above parasites. Cotton plants which were dead, wilted, or showing blackened vascular systems were considered to be invaded by *F. vasinfectum*. Of course this assumption is not strictly valid and therefore a map made by the above methods is not wholly accurate. The writers believe, however, that perhaps many of the plants in the above classification were at some time during the season invaded by *F. vasinfectum*. Because the distribution of plants in the above classification was general over the field both seasons and because no accurate information could be made available on the exact numbers of plants invaded by *F. vasinfectum*, the disease distribution maps are not reproduced herewith for comparative study. An accurate distribution map for *F. vasinfectum* would involve isolation of the parasite from a large number of plants and reproduction of pathogenicity from the cultures obtained. Although such detailed investigations were not possible during the course of this investigation, the writers believe that the field chosen for this work was sufficiently infested with *F. vasinfectum* for the purpose of this paper. Additional evidence on this phase of the work will be presented below.

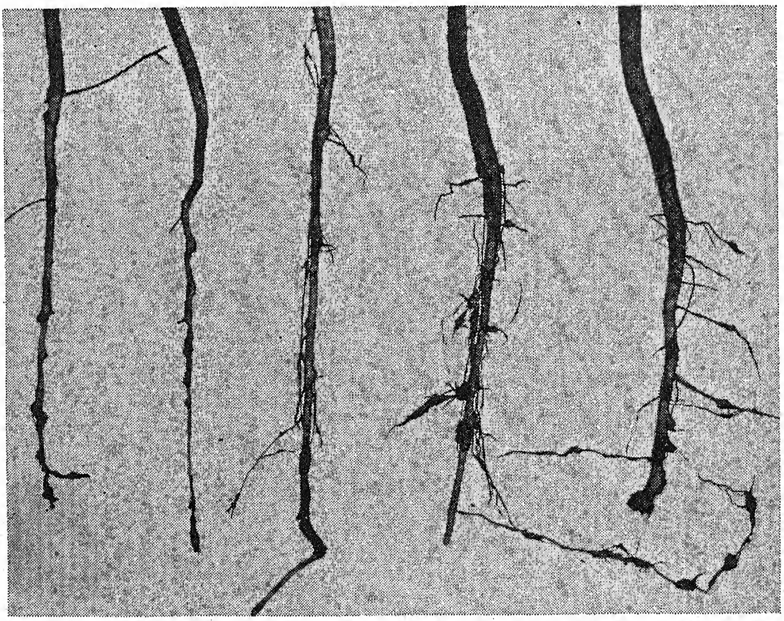


FIG. 1.—Damage (severe) caused by the root-knot nematode, *Heterodera marioni* (Cornu) Goodey, to cotton roots growing on unfertilized untreated Sarpy fine Sandy loam. Reduced.

After data were collected on the occurrence of dead plants, wilted plants, and plants with blackened vascular systems, the roots were plowed out and examined for root-knot galls.

Methods of recording the results of the work completed on Sarpy fine sandy loam consisted of harvesting and weighing the seed cotton produced on the center three rows of each five-row plot, cutting and examining the stalks and roots after harvest, and recording general notes throughout the season concerning disease and plant development. Other notes pertinent to the results obtained are included at appropriate places in this paper.

The variety of cotton used on all of these plots throughout the 3-year study at Stoneville was Delfos 3506, which is a fusarium wilt susceptible type widely grown on alluvial soils.

TABLE 1.—*Randomized field plot arrangement of the fusarium wilt-nematode experiments on Sarpy fine sandy loam for the period 1940 to 1942, inclusive. Stoneville, Miss.*

Range	Series A	Range	Series B	Range	Series C	Range	Series D
1	Stable manure, 4 tons on surface	6	Dry sagrain + $(NH_4)_2SO_4$ (30 lbs. N_2) in furrows	9	Cotton stalks in furrows	4	Nontreated
2	Stable manure, 8 tons in furrows	5	Rotted alfalfa hay in furrows	4	Nontreated	7	Cyanamid (30 lbs. N_2) in furrows
3	Stable manure, 8 tons on surface	4	Nontreated	8	Cyanamid (60 lbs. N_2) in furrows	11	Cyanamid (90 lbs. N_2) in furrows
4	Nontreated	1	Stable manure, 4 tons on surface	5	Rotted alfalfa hay in furrows	8	Cyanamid (60 lbs. N_2) in furrows
5	Rotted alfalfa hay in furrows	10	Stable manure, 4 tons in furrows	12	Nontreated	2	Stable manure, 8 tons in furrows
6	Dry sagrain + $(NH_4)_2SO_4$ (30 lbs. N_2) in furrows	11	Cyanamid (90 lbs. N_2) in furrows	1	Stable manure, 4 tons on surface	6	Dry sagrain + $(NH_4)_2SO_4$ (30 lbs. N_2) in furrows
7	Cyanamid (30 lbs. N_2) in furrows	9	Cotton stalks in furrows	3	Stable manure, 8 tons on surface	12	Nontreated
8	Cyanamid (60 lbs. N_2) in furrows	7	Cyanamid (30 lbs. N_2) in furrows	2	Stable manure, 8 tons in furrows	1	Stable manure, 4 tons on surface
9	Cotton stalks in furrows	3	Stable manure, 8 tons on surface	6	Dry sagrain + $(NH_4)_2SO_4$ (30 lbs. N_2) in furrows	5	Rotted alfalfa hay in furrows
10	Stable manure, 4 tons in furrows	12	Nontreated	7	Cyanamid (30 lbs. N_2) in furrows	3	Stable manure, 8 tons on surface
11	Cyanamid (90 lbs. N_2) in furrows	8	Cyanamid (60 lbs. N_2) in furrows	10	Stable manure, 4 tons in furrows	9	Cotton stalks in furrows
12	Nontreated	2	Stable manure, 8 tons in furrows	11	Cyanamid (90 lbs. N_2) in furrows	10	Stable manure, 4 tons in furrows

RESULTS

RUSTON SANDY LOAM, POPLARVILLE, MISS.

Eight years of continuous cotton fertilization using medium to high rates of application of stable manure compared with a 6–8–4 commercial fertilizer showed rather high yields for both materials on Ruston sandy loam. Table 2 gives in detail the yearly average for all plots. Four or more tons of stable manure per acre outyielded

all of the commercial fertilizer plots up to and including the 1,200-pound applications of 6–8–4.

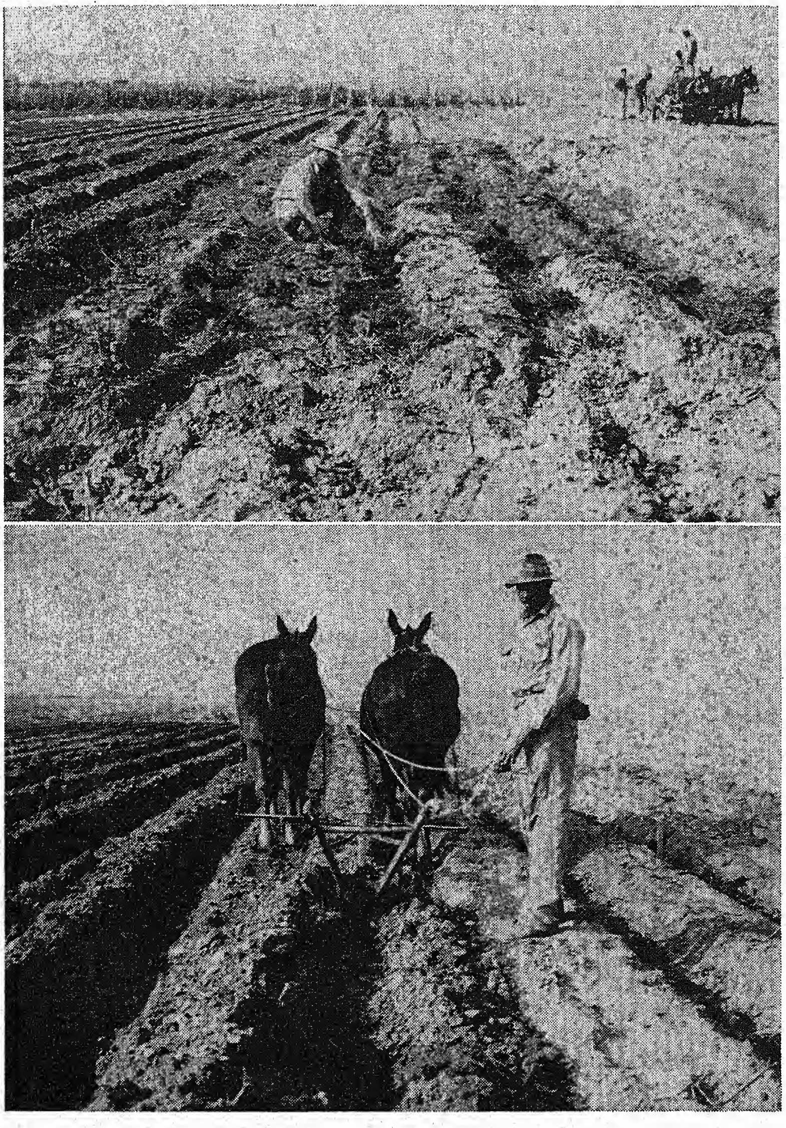


FIG. 2.—Method of incorporating organic amendments in the soil under the rows. *Above*, spoiled alfalfa hay, distributed in furrows 10 inches deep; *Below*, middle buster method of covering organic amendments. Stoneville, Miss., February, 1943.

Ten years of continuous fertilization in the above manner seems to have had little apparent effect upon the total fusarium wilt in-

TABLE 2.—*Average annual yield in pounds of seed cotton per acre as affected by stated soil amendments applied to Ruston sandy loam infested with Fusarium vasinfectum and Heterodera marioni, Poplarville, Miss.**

Soil amendment and amount per acre†	Yield of seed cotton per acre, lbs.								
	1933	1934	1935	1936	1937	1938	1939	1940	Av.
Stable manure, 10 tons	914	1,066	1,066	1,496	906	1,104	986	2,124	1,208
Stable manure, 12 tons	1,100	1,184	1,370	1,508	874	784	848	1,780	1,181
Stable manure, 8 tons	880	986	834	1,424	876	1,284	865	1,926	1,134
Stable manure, 6 tons	794	932	744	1,184	790	1,288	731	1,632	1,012
Stable manure, 4 tons	800	904	744	1,212	914	1,234	671	1,360	980
Commercial fertilizer, 1,200 lbs. 6–8–4	1,106	864	632	1,156	886	334	466	1,378	853
Commercial fertilizer, 800 lbs. 6–8–4	860	946	726	1,096	954	620	338	1,286	853
Commercial fertilizer, 1,000 lbs. 6–8–4	946	902	428	1,136	990	498	450	1,354	838
Commercial fertilizer, 600 lbs. 6–8–4	954	882	596	964	918	830	303	1,121	821
Stable manure, 2 tons	640	690	586	904	726	1,042	425	960	746
Commercial fertilizer, 400 lbs. 6–8–4	866	680	500	1,084	716	952	270	800	733
Commercial fertilizer, 200 lbs. 6–8–4	654	618	306	732	696	896	256	770	616
None‡	406	460	158	328	379	547	158	535	372

*Variety Delta and Pine Land 26-5C-6A.
†Application of fertilizers made at planting time; materials buried deep in furrows.
‡Average of eight untreated plots.

fection and upon the total severity and distribution of the root-knot nematode. Table 3 summarizes these studies. The average wilt

TABLE 3.—*Average percentage of fusarium wilt infection, severity of root-knot infestation, yield, height, and diameter of cotton plants in 1942 in relation to the cumulative effect of 10 years continuous fertilization and with winter legumes, Ruston sandy loam, Poplarville, Miss.*

Treatment	Average wilt infection, %*	Estimated nematode infestation†	Average height, in.	Average diameter, mm.	Eight-year average yield of seed cotton, lbs.‡
Stable manure, 10 tons	67.0	3.0	65	22	1,208
Stable manure, 12 tons	58.0	3.0	63	27	1,181
Stable manure, 8 tons	67.0	2.0	59	23	1,134
Stable manure, 6 tons	59.0	2.5	50	18	1,012
Stable manure, 4 tons	63.0	3.0	49	16	980
6–8–4, 1,200 lbs.	69.0	2.0	49	20	853
6–8–4, 800 lbs.	65.0	3.0	51	19	853
6–8–4, 1,000 lbs.	65.0	3.0	56	21	838
6–8–4, 600 lbs.	68.0	2.0	47	16	821
Stable manure, 2 tons	58.0	2.0	42	14	746
6–8–4, 400 lbs.	65.0	2.0	41	17	733
6–8–4, 200 lbs.	72.0	3.0	38	12	616
Nontreated check	53.0	2.5	32	11	372

*200 plants examined.
†200 plants examined and classified as follows: 0 (none), 1 (moderate), 2 (serious), or 3 (severe).
‡1933 to 1940, inclusive.

infection of all plots was uniformly high, although the untreated check plot was slightly lower than all others. No significant relation seemed to exist between nematode infestation and plot treatment; all were uniformly severe. Increasing fertilization rates increased the average height of the plants and average diameters of stems. Stable manure seemed to produce plants somewhat larger in diameter and of considerably better late season appearance. Yields resulting from the stable manure applications were considerably higher than those receiving commercial fertilizers. The reasons for this difference afford interesting speculation because these plots were rather uniformly infested with two soilborne diseases.

The residual fertilizer effect of 10 years continuous fertilization and cotton culture in rotation with winter legumes on these plots was thought to be considerable in some instances. Although it was not practical to measure quantitatively the plant food present in the above plots, an indication of fertility was obtained by seeding all plots to oats in the fall of 1942. A fairly uniform stand was obtained and by February 15, the oats had covered the ground and made substantial growth except in the plots receiving low rates of fertilizers. Table 4 shows the average estimated growth of oats in inches on February 15, and Fig. 3 shows a representative portion of three plots, untreated check, 800 pounds of 6–8–4 commercial fertilizer, and 10 tons of stable manure. The results of these studies show the same general trend with oats as with cotton, the largest growth of green material being associated with the high fertilizer rates, but with the greatest growth being

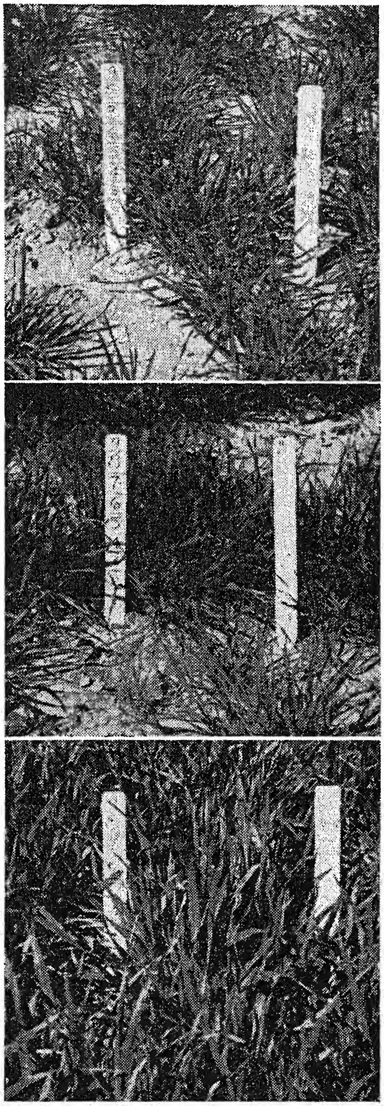


FIG. 3.—Residual plant food remaining in certain field plots of Ruston sandy loam as indicated by growth of oat plants. *Upper*, untreated control; *middle*, 800 pounds of 6–8–4; *lower*, 8 tons stable manure. Poplarville Miss., 1943.

made on the manured plots. The oat plant not being susceptible to either *Fusarium vasinfectum* or *Heterodera marioni* thus indicated, in a general way, the potential fertility of the field plots uncomplicated by these diseases.

TABLE 4.—*Estimated height in inches of oat plants on wilt-nematode plots, Ruston sandy loam, Poplarville, Miss., 1943.**

Treatment	Av. height, in.
Stable manure, 12 tons	12
Stable manure, 10 tons	11
Stable manure, 8 tons	11
Stable manure, 6 tons	8
Stable manure, 4 tons	6
Stable manure, 2 tons	4
6–8–4, 1,200 lbs	7
6–8–4, 1,000 lbs	7
6–8–4, 800 lbs	6
6–8–4, 600 lbs	6
6–8–4, 400 lbs	4
6–8–4, 200 lbs	4
Untreated	4†

*Data taken Feb. 15, 1943.
†Average of eight untreated plots.

An important observation resulting from these studies seemed to be the demonstrated inability of either the fertilizer or manurial treatments to prevent infection by *F. vasinfectum* or *H. marioni*; and the further inference that rather high yields of seed cotton were made consistently although the two diseases were present in considerable amounts.

TABLE 5.—*Average annual yield in pounds of seed cotton per acre as affected by stated soil amendments applied to Sarpy fine sandy loam infested with Fusarium vasinfectum and Heterodera marioni, Stoneville, Miss., 1940 to 1942, inclusive.**

Soil amendment and amount per acre	Method of application†	Yield of seed cotton per acre, lbs.			
		1940	1941	1942	Av.
Alfalfa hay, spoiled‡	In furrow	1,602	1,558	1,706	1,622
Stable manure, 8 tons	In furrow	1,540	1,711	1,400	1,550
Stable manure, 4 tons	In furrow	1,650	1,312	1,375	1,445
Stable manure, 8 tons	On surface	1,533	1,305	1,472	1,437
Cyanamid (90 lbs. N_2)	In furrow	1,657	1,108	1,112	1,292
Dry sagrain + ammonium sulfate (30 lbs. N_2)‡	In furrow	1,605	1,000	1,224	1,276
Stable manure, 4 tons	On surface	1,337	1,053	1,429	1,273
Cyanamid (30 lbs. N_2)	In furrow	1,503	1,018	1,182	1,234
Cyanamid (60 lbs. N_2)	In furrow	1,533	878	1,002	1,137
Cotton stalks‡	In furrow	1,371	1,049	828	1,083
Nontreated§	None	1,128	734	938	933

*Variety Delfos 3506.
†January or February.
‡Furrows filled, then tramped (see text).
§Average of eight untreated plots.

SARPY FINE SANDY LOAM, STONEVILLE, MISS.

The yield in pounds of seed cotton per acre resulting from the various soil treatments applied to Sarpy fine sandy loam is tabulated in Table 5. Spoiled alfalfa hay gave the greatest 3-year average yield of seed cotton, while cotton stalks and the untreated check plots gave the lowest. Eight tons of stable manure buried in the furrows was nearly as good as the spoiled alfalfa hay. Four tons of stable manure in the furrows were equivalent to 8 tons used as a top dressing. Cyanamid equivalent to 30 pounds of nitrogen per acre was almost equivalent to 4 tons of stable manure, if used as a top dressing, and to dry sagrain enriched with ammonium sulfate. All cyanamid nitrogen applications gave high yields the first year, but in the third year cyanamid gave the lowest yields of all treatments except cotton stalks. In 1942 all of the cyanamid plots showed injury similar to that caused by potash deficiency; later, defoliation became serious on plots receiving the 60 and 90 pound rates. The use of cotton stalks in the furrows failed to increase wilt damage or to bring about a noticeable change in the amount of disease present.

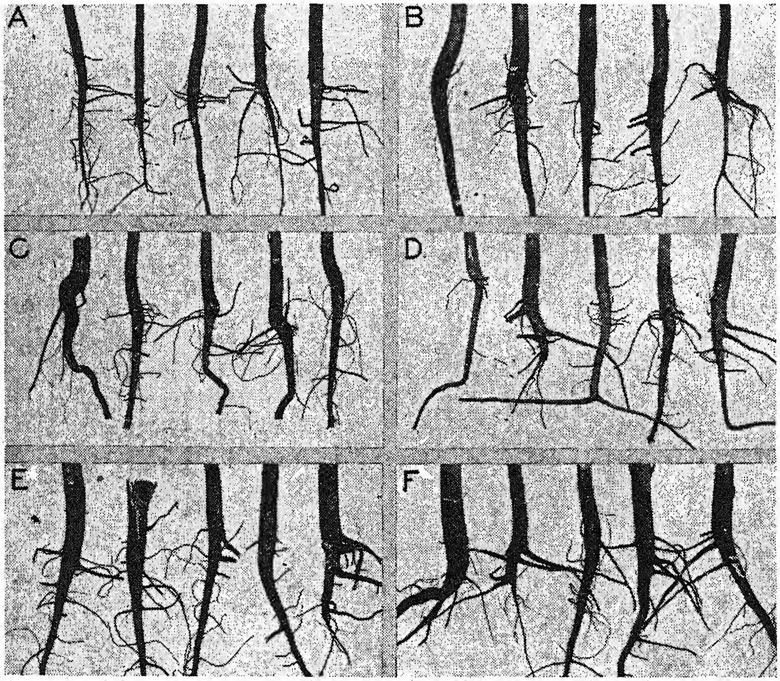


FIG. 4.—Roots of cotton collected from Sarpy fine sandy loam field plots receiving stated soil treatments 3 consecutive years. A, non-treated; B, cyanamid, 60 pounds of nitrogen per acre; C, cotton stalks packed in furrows; D, dry sagrain, *Sorghum vulgare*, packed in the furrows; E, stable manure, 8 tons per acre; F, spoiled alfalfa hay. All photographs made with a fixed focus to show relative size. Stoneville, Miss., September, 1942.

The effect of the several soil amendments on the development and gross morphology of cotton roots is illustrated in Fig. 4. Nontreated or unfertilized check plots produced the smallest plants with the smallest roots. These roots appeared to be morphologically normal in that well-developed tap roots were formed unless attacked by disease-producing microorganisms. The nematode infestation of the soil, though fairly uniform, was considered to be slight. The infestation was sufficient to bring about some infection on nearly all plants but severe damage was limited in these plots. Cyanamid at the rate of 60 pounds of nitrogen per acre produced well-developed tap roots but few large laterals. Spoiled alfalfa hay and stable manure in the furrows produced the largest and most branched roots of all treatments. Sagrain and cotton stalks resulted in high percentages of bent and irregular tap roots, with no special increase in the size or number of lateral roots. These organic nitrogenous materials were in sufficient abundance under the rows to provide an excellent medium for lateral root development. Considerable fiberous residues of these materials were recovered from the soil 9 months after their application.

FIG. 5.—Effect of manurial treatment on the fruiting of cotton affected with the Fusarium-Heterodera complex. *Left*, stable manure, 8 tons per acre broadcast (series B, range 3); *right*, nontreated (series B, range 12). Stoneville, Miss., September 11, 1941.

The effect of the various treatments on the above-ground or overall appearance of the plants in these plots was very striking each year. Fig. 5 illustrates the difference in fruiting between an untreated check plot and an adjoining plot receiving 8 tons of stable manure on the surface. In addition to differences in fruiting which are given in terms of yield in Table 5, there were differences in average height, color of leaves, and numbers of dead plants at harvest. In addition, serious defoliation and many dead plants were noted on plots receiving cyanamid.

No relation seemed apparent between the *total* amount of fusarium wilt present and the several soil treatments, although a very definite relation was consistently observed between soil treatment and ability

of plants to survive and bear fruit although infected with fusarium wilt and root-knot nematode.

OCCURRENCE OF VASCULAR PARASITES WITHIN THE PLANTS

In these studies it was not feasible to maintain a close record of disease development within the individual plots throughout the season. Either external symptoms or blackened vascular systems, or both characters, were considered evidence of fusarium wilt infection. Plants killed before frost but still standing were assumed to have succumbed either because of *Fusarium vasinfectum* or because of root-knot. These assumptions, though not strictly valid, appeared to approximate the situation on the Ruston and Sarpy soil series. Isolations from blackened stem sections of cotton stems collected during and after harvest from various sources in central and south Mississippi in 1943 were made. These showed 50% of the blackened stems to contain fusarial species indistinguishable from *F. vasinfectum* in culture. Thirty-five per cent of the tissue platings gave *Sclerotium bataticola*, 3.5% unidentified microorganisms, and 17% remained sterile. Isolations from nearly 300 normal-appearing cotton stem sections were made along with the above isolations to test the possibility of secondary organisms being present but not visible. *S. bataticola* appeared in a few instances in yellowish stem sections removed from dead plants. It should be pointed out that *S. bataticola* and certain unidentified fungi were frequently found associated in the same tissue platings with fusarium.

The presence of a blackened vascular system, which has long been considered to be a symptom of both fusarium and verticillium wilt, is regarded here as being a sign that the plant was at one time invaded by either of the above parasitic fungi. The black vascular system does not seem to be the result of secondary nonparasitic invaders if the plant be partially alive at the time of sampling. After plants have been dead for some time of course no conclusions seem valid.

In presenting the results of this investigation the writers made no distinction between degree of infection among the plants. Any positive symptom of fusarial infection, however slight, was regarded as potentially harmful to the plant. For this reason wide distribution of fusarium wilt appeared over the fields. Because laboratory isolations from this and similar material showed that 50% of the plants having blackened vascular systems carried species of fusaria indistinguishable in culture from *Fusarium vasinfectum*, the writers conclude that the disease-producing agent was probably quite wide-spread in the fields under investigation. Final proof of this assumption rests upon proving the pathogenicity of each culture isolated. Unfortunately, facilities for this phase of the work were not available.

DISCUSSION

The use of stable manure or other similar organic materials under cotton is not new. Before the introduction of concentrated chemical fertilizers it was common farm practice to prepare a compost for use in the furrows under the plants (11). Experience had no doubt proved

this practice to be superior to broadcast methods of application. Later, however, work by Smith and Camp (9) in the sand hill section of South Carolina demonstrated the value of manure, both drilled and broadcast, under cotton. It is possible that Smith and Camp were dealing in part with cotton wilt. King and Loomis (4) demonstrated the value of both manure and green alfalfa hay for the control of cotton root-rot in Arizona and noted that the organic materials improved lateral and fibrous root development. These workers concluded that although the organic amendments used did not exterminate the parasite, they enabled the plants to withstand attack by the organism. Additional work on the cotton root-rot disease by King and associates (5, 6) and by Clark (2) showed that organic amendments added to root-rot infested soils encouraged increased biological activity which resulted in partial destruction of the parasite.

Young and Tharp (12), and others, have shown that potash reduces the incidence of wilt on certain soils, while Tisdale and Dick (10) report experiments some of which confirm the value of potash and in some of which potash had little effect in preventing mid-season wilt. In this connection it is interesting to review briefly the specific effect that a deficiency of potash has on plants. Nightingale and associates (7) found that in plants deficient in potash the cambial activity ceased, but some apical growth continued; the net result in sweetpotatoes and beets being slender roots. If a deficiency of potash has similar effects on cotton, it is easy to visualize how host development is reduced while parasitism, however weak it may be, could continue to some degree so long as carbohydrates and some nitrogenous materials remain in the roots.

Up to the time of fruiting, intake of nutrients from the soil may be rapid enough to promote sufficient cambial activity to enable the plant to wall off or out-grow *Fusarium vasinfectum*, and commonly enough, cotton wilt makes its first general appearance shortly after blossom formation.

Because the process of fruiting appears to compete with and become dominant over vegetative growth and root development (3), a fruiting plant could be expected to have either a reduced rate of vegetative growth, or none, depending upon the adequacy of plant food, the plant food supplying power of the soil, and the ability of absorbing rootlets to function. If the absorbing rootlets are parasitized by one or more soil-borne pathogens, host development may be reduced by a combination of events. Plants growing on damp locations, on clay soils, and along ends of rows terminating on plot roads may be invaded early in life by *F. vasinfectum* but finally produce a heavy set of bolls and unusual vegetative growth. These conditions obviously favor root development, or regeneration. In sandy soils where plant food is naturally low and where soluble concentrated fertilizers may be quickly leached, the maximum rate of root development cannot be long maintained. Furthermore, drouth conditions develop quickly in sandy soils, and even though an abundance of plant food be available, root development is retarded.

Root elongation and development in cotton is extremely rapid, at least during the early life of the plant. Brown and others (1) report

that under favorable conditions cotton roots may lengthen ½ inch per day. Observations by the writers on cotton root development indicate that the plant does make a phenomenally rapid root growth under optimum conditions. Such conditions were approximated on Ruston sandy loam in plots receiving high rates of manure in 1942. Approximately 50 inches of terminal growth was made in 150 days even though both root-knot and fusarium wilt were present. It is difficult to imagine *Fusarium vasinfectum* bringing about damage in plants of this kind without the assistance of other limiting or partially limiting factors.

The writers are inclined to the view that unfavorable conditions for cotton root development in the field predisposes the plant to destruction by *F. vasinfectum* and perhaps by other soil-borne parasites, and that the commonly observed highly variable nature of the disease can be explained only by an understanding of those factors which influence cambial activity and root development.

The results reported in this paper on both Ruston and Sarpy soils do not indicate that any of the organic amendments or soil treatments used had a measurable influence upon the amount of *total* infection, although some of the treatments enabled the plants to withstand parasitism and produce an almost normal crop of seed cotton. In the opinion of the writers, the value of manure and alfalfa composts lies in the ability of these materials to offer the plants a slowly available source of plant food while at the same time improving the physical structure of the root-absorbing region of the soil. By improving this region of the soil a more branching type of cotton root system was developed which seemed to have an advantage over the less well-developed root systems.

Practical field considerations indicate that the use of large quantities of nitrogenous organic residues, such as stable manure or spoiled alfalfa hay drilled under cotton, while ineffective in preventing infection by *Fusarium vasinfectum* and *Heterodera marioni*, may nevertheless improve yields of seed cotton to a level nearly equal to those on disease-free soils. It is realized that the quantities of manure or legume hay required for this purpose are not generally available to farmers under the present agricultural methods. It is suggested herewith that by improving the culture of winter legumes and plowing down the vines in such manner that the bulk of the vegetation be placed under the future cotton row that considerable benefit in yield of seed cotton should result on wilt-infested soils.

SUMMARY

A study has been made of the effect of several organic soil amendments on the yield of cotton grown on Mississippi soils with *F. vasinfectum* and *H. marioni.* Eight years continuous cotton culture on Ruston sandy loam fertilized variously with stable manure and commercial 6–8–4 mixtures were compared. Four or more tons of stable manure per acre outyielded all of the commercial fertilizer plots up to and including the 1,200-pound application of 6–8–4. All materials were placed in the drill row.

Spoiled alfalfa hay drilled, stable manure drilled and broadcast, cyanamid, sagrain, and cotton stalks drilled in the rows before planting were used on Sarpy fine sandy loam for 3 years. The alfalfa hay and stable manure, if drilled, outyielded all other material used. Use of diseased cotton stalks failed to increase wilt.

Neither total amount of infection nor the distribution of *Fusarium vasinfectum* and *Heterodera marioni* on the Ruston and Sarpy soil series was influenced by any of the treatments. The average annual yield of seed cotton, however, was markedly influenced by certain treatments, except by low amounts of fertilizers and by cotton stalks. Although a high proportion of plants on all plots were invaded by *F. vasinfectum* and *H. marioni*, little damage appeared among plants growing on the plots receiving high rates of organic manures.

The writers suggest that unfavorable conditions for cotton root development in the field predisposes the plants to destruction by *F. vasinfectum* and that the commonly observed highly variable nature of the disease can be explained only by an understanding of those factors which influence root development. The writers also suggest that improving the culture of winter legumes and plowing down the vines, throwing the bulk of the vegetation under the future cotton rows, may prove effective in reducing wilt.

LITERATURE CITED

1. BROWN, H. B., SIMON, E. C., and SMITH, A. K. Cotton root development in certain south Louisiana soils. La. Sta. Bul. 232. 1932.

2. CLARK, FRANCIS E. Experiments toward the control of the take-all disease of wheat and the Phymatotrichum root rot of cotton. U.D.S.A. Tech. Bul. 835. 1942.

3. EATON, FRANK M. Root development as related to character of growth and fruitfulness of the cotton plant. Jour. Agr. Res., 43:875–883. 1931.

4. KING, C. J., and LOOMIS, H. F. Experiments on the control of cotton root rot in Arizona. Jour. Agr. Res., 32:297–310. 1926.

5. ————, ————. Further studies of cotton root rot in Arizona with a description of a sclerotium stage of the fungus. Jour. Agr. Res., 39:641–676. 1929.

6. ————, HOPE, CLAUDE, and EATON, E. D. Some microbiological activities affected in manurial control of cotton root rot. Jour. Agr. Res., 49: 1093–1107. 1934.

7. NIGHTINGALE, G. T., SCHERMERHORN, L. G., and ROBBINS, W. R. Some effects of potassium deficiency on the histological structure and nitrogenous and carbohydrate constituents of plants. N. J. Agr. Exp. Sta. Bul. 499. 1930.

8. PINCKARD, J. A., LEONARD, O. A., and MCNAMARA, H. C. Influence of certain soil amendments on the yield of cotton affected by the Fusarium-Heterodera complex. Phytopath., 33:10. 1943.

9. SMITH, A. G., and CAMP, OTIS O. Some experiments on sand hill land tillage, fertilizer, and crop adaptation. S. C. State Dept. Agr. Bul. 63. 1918.

10. TISDALE, H. B., and DICK, J. B. Cotton wilt in Alabama as affected by potash supplements and as related to varietal behavior and other important agronomic problems. Jour. Amer. Soc. Agron., 34:405–426. 1942.

11. TRUE, A. C. The cotton plant: Its history, botany, chemistry, culture, enemies, and uses. U.S.D.A. Office Exp. Sta. Bul. No. 33. 1896.

12. YOUNG, V. H., and THARP, W. H. Relation of fertilizer balance to potash hunger and the fusarium wilt of cotton. Ark. Agr. Exp. Sta. Bul. 410. 1941.

THE INHERITANCE OF FLOWER FRAGRANCE AND OTHER CHARACTERS IN RICE[1]

N. E. JODON[2]

AN ODOR, light but distinctly sweet and suggestive of violets, was discovered by the writer in the flowers of the rice variety C. I. 3794, an introduction from the Philippines. Flower fragrance in gramineae, of a type that might attract insects for pollination, is undoubtedly rare. Certain genera contain aromatic substances which may be emitted by the flowers, although not limited to the floral organs. Such substances may have a protective role, not aiding in pollination. Scented or aromatic rices sometimes emit an odor while blooming (8, 10)[3] and the milled rice has a distinctive popcorn-like or nutty flavor, much prized in the Orient and in this country by some consumers. The milled grain of C. I. 3794 apparently has the same flavor as other nonscented rices. No obvious floral organ, serving as a nectary, has been found and the source of the floral fragrance has not been determined.[4]

This paper presents data on the inheritance of the flower fragrance of C. I. 3794 and six other characters.

MATERIALS AND METHODS

Crosses were made between C. I. 3794 and Fortuna and Delitus. The latter is a scented rice, but the scented character did not interfere with the classification of segregating progeny for flower fragrance. The F_2 populations were grown in space-sown plots. Plants were examined daily during the blooming period for flower fragrance, and their classification was recorded on tags attached to each Plant. Fragrance was discernible only while florets were in bloom, or shortly thereafter, a period of about 2 hours each morning. It was easiest to identify fragrant segregates when many florets on a panicle were in bloom.

One panicle from each F_2 plant was harvested and used in the classification of the other characters studied, except Cercospora resistance and time of maturity. The methods of checking for Cercospora resistance in the field has been reported by Ryker and Jodon (11). Maturity data were obtained from F_3 rows.

In 1942, the F_3 progenies were grown in single-rod rows with the plants thinned. In the cross C. I. 3794 × Fortuna, progeny rows were classed as early; that is, of approximately the same maturity as C. I. 3794, intermediate or segregating, and midseason or of approximately the same maturity as Fortuna. In the cross C. I. 3794 × Delitus, fragrance was checked only in the F_3 progeny.

The contrasting characters studied are shown in Table 1.

REVIEW OF LITERATURE

Hebert (4), Breaux (2), and de la Houssaye (5) reported a 3:1 ratio for straw vs. gold inner glumes, and Hebert (4) reported 3:1 and 27:37 ratios for full vs. nonfull purple inner and outer glumes. Pubescence was found to be dominant to

[1]Contribution from the Division of Cereal Crops and Diseases, Bureau of Plant Industry, Soils, and Agricultural Engineering, Agricultural Research Administration, U. S. Dept. of Agriculture, and the Louisiana Agricultural Experiment Station, cooperating. The work was conducted at the Rice Experiment Station, Crowley, La. Received for publication July 11, 1944.

[2]Associate agronomist, Division of Cereal Crops and Diseases.

[3]Figures in parenthesis refer to "Literature Cited", p. 848.

[4]Dr. E. C. Tullis, kindly made microscopic examinations of florets of C. I. 3794 and other varieties.

glabrous hulls and 3:1 ratios were reported by Hebert (4), Breaux (2), and Codd (3). Resistance to *Cercospora oryzae* was reported by Adair (1) and Ryker and Jodon (11) to be due to a single dominant factor. Jodon, Ryker, and Chilton (6) reported duplicate factor ratios also.

Earlier literature referring to these characters in rice was listed by Jones (7). For purple inner glumes, a ratio of 27:37; for outer glume color, 3:1 and 9:7; for straw vs. gold hull color 3:1; and for maturity, 3 late to 1 early, 3 early to 1 late, and 9 late to 7 early plants were reported.

In gladiolus, McLean (9) studied two differently inherited types of fragrance. A violet-like fragrance was dominant and dependent on two factors.

TABLE 1.—*Contrasting characters studied.*

C. I. 3794	Fortuna	Delitus
Fragrant flower	Nonfragrant	Nonfragrant
Glabrous inner glumes	Pubescent inner glumes	Pubescent inner glumes
Gold inner glumes	Straw inner glumes	———
Cercospora resistant	Cercospora susceptible*	———
Purple inner glumes	Purple apiculus and apex	Faint purple apiculus
Purple outer glumes	———	Nonpurple outer glumes
Medium early maturity	Midseason maturity	———

*Susceptible to race 4.

RESULTS

Flower fragrance of the F_1 plants at blooming time was similar to that of C. I. 3794. In one F_2 family of the cross C. I. 3794 × Fortuna, grown in 1939, 134 plants were classed as fragrant and 124 as nonfragrant. In another F_2 family from the same cross, grown in 1941, 41 plants were classed as fragrant, 42 questionably fragrant, and 74 nonfragrant. If the 42 questionable plants are classed as fragrant, the results indicate complementary factors giving a 9:7 ratio. The results from F_3 progenies, however, show that many fragrant plants were not identified as such in the F_2 and therefore fragrant segregates were in excess of the number expected on the basis of a 9:7 ratio in F_2. Natural crosses on nonfragrant F_2 plants probably caused a few genotypically nonfragrant F_3 progenies to be classed as fragrant.

The F_2 segregation, as corrected from F_3 breeding behavior, is shown in Table 2. The data indicate that in both crosses segregation for flower fragrance was in agreement with a 3:1 ratio. Agreement with expected ratios previously reported was satisfactory for six of the seven other characters studied. For Cercospora resistance, the F_2 data indicate better agreement with a 15:1 than a 63:1 ratio, but on the basis of proportions of homozygous and segregating F_3 rows it appears probable that the latter ratio is correct, as reported by Jodon, *et al* (6).

Three of the contrasting characters studied occurred in both crosses. In the cross C. I. 3794 × Fortuna, pubescence vs. glabrous, segregated in a single factor ratio, and in the cross with Delitus probably in a 15:1 ratio. In the latter cross, there were 42 homozygous pubescent, 26 segregating, and 9 homozygous glabrous, which agrees satisfactorily with the numbers expected for a 9:6:1 ratio. Chi square is 4.005 and P is between 0.20 and 0.10. As shown in Table 2, however, the agreement with a 15:1 ratio is only fair. A

modifying factor rather than duplicate factors may be responsible for the deviation from the 3:1 ratio.

TABLE 2.—*Segregation in F_2 of fragrance and other characters in two rice crosses.*

Character pairs	Number		Ratio	Chi square*
	Dominant	Recessive		
C.I. 3794×Fortuna				
Fragrant vs. nonfragrant	128	29	3:1	3.569
Pubescent vs. glabrous	119	38	3:1	0.053
Straw vs. gold glumes	123	34	3:1	0.936
Cercospora resistant vs. susceptible	150	7	63:1†	8.561
Fully purple inner glumes vs. purple apiculus and apex	63	94	27:37	0.268
Late vs. early	115	42	3:1	0.257
C.I. 3794×Delitus				
Fragrant vs. nonfragrant	61	17	3:1	0.427
Pubescent vs. glabrous	69	9	15:1	3.723
Fully purple inner glumes vs. nonfully purple	32	46	27:37	0.043
Purple outer glumes vs. nonpurple	62	16	3:1	0.838

*5% point is 3.841.
†F_3 data indicate 63:1 ratio more probably than 15:1 (6).

Although in both crosses 27:37 ratios were obtained for inner glume color, the factors involved cannot be identical. In the cross C. I. 3794 × Delitus, three factors control a difference between full-purple inner glumes vs. faint purple apiculus only; whereas, in the cross C. I. 3794 × Fortuna, three factors control the difference between full-purple vs. purple apiculus and apex. Both parents of the cross C. I. 3794 × Fortuna had purple outer glumes, but in Delitus they are colorless.

The cross C. I. 3794 × Delitus was classified in three groups, *viz.*, (a) purple inner and outer glumes; (b) purple apiculus, apex, and outer glumes; and (c) faint purple apiculus with colorless outer glumes. There were 32, 30, and 16 F_2 plants in the respective classes, whereas, the expected numbers for a 27:21:16 ratio were 32.9:25.6:19.5. Chi square is 1.409 and P is between 0.50 and 0.30. By combining (a) the first and second groups for outer glume color, a 3:1 ratio, and (b) the second and third groups for full-purple vs. nonfull purple inner glumes, a 27:37 ratio was obtained.

In the cross C. I. 3794 × Fortuna, straw vs. gold hulls and late vs. early maturity segregated in 3:1 ratios. There were 42 early, 93 segregating, and 22 midseason F_3 progenies. Although this agrees poorly with a 1:2:1 ratio, when the midseason and segregating classes are combined, the agreement with a 3:1 ratio of late to early is good.

A total of 10 factors, therefore, appear to control the inheritance of the 6 characters studied in the cross C. I. 3794 × Fortuna, and in the cross C. I. 3794 × Delitus, 6 factors control 4 characters.

Table 3 presents Chi square tests for goodness of fit for combined ratios of pairs of characters in all possible combinations. There were

TABLE 3.—*Chi square tests for goodness of fit for inter se combinations of F_2 ratios of seven characters in the rice crosses of C.I. 3794×Fortuna and C.I. 3794×Delitus.*

Character pairs	Ratios combined	Numbers observed (above) and expected (below)	Chi square goodness of fit*
Fragrant vs. nonfragrant with:			
Pubescent vs. glabrous	3:1 and 3:1	93:35:26:3 88.3:29.4:29.4:9.8	6.431
	3:1 and 15:1†	54:7:15:2 54.8:3.7:18.3:1.2	4.083
Straw vs. gold hull	3:1 and 3:1	105:23:18:11 88.3:29.4:29.4:9.8	0.928
Cercospora resistant vs. susceptible	3:1 and 63:1	122:6:28:1 115.9:1.9:38.6:0.6	12.106 (0.852)‡
Purple vs. colorless inner glumes	3:1 and 27:37	47:81:16:13 49.7:68.1:16.5:22.7	6.751
	3:1 and 27:37†	27:34:5:12 24.7:33.8:8.2:11.3	1.507
Midseason vs. early	3:1 and 3:1	95:33:20:9 88.3:29.4:29.4:9.8	4.030
Purple vs. colorless outer glumes	3:1 and 3:1†	46:15:16:1 43.9:14.6:14.6:4.9	3.322
Pubescent vs. glabrous with:			
Straw vs. gold hull	3:1 and 3:1	91:28:32:6 88.3:29.4:29.4:9.8	1.826
Cercospora resistant vs. susceptible	3:1 and 63:1	115:4:35:3 115.9:1.9:38.6:0.6	12.264 (1.390)‡
Purple vs. colorless inner glumes	3:1 and 27:37	54:65:9:29 49.7:68.1:16.5:22.7	5.670
	15:1 and 27:37†	29:40:3:6 30.8:42.3:2.1:2.8	4.273
Midseason vs. early	3:1 and 3:1	90:29:25:13 88.3:29.4:29.4:9.8	1.743
Purple vs. colorless outer glumes	15:1 and 3:1	56:13:6:3 54.8:18.3:3.7:1.2†	5.691
Straw vs. gold hull with:			
Cercospora resistant vs. susceptible	3:1 and 63:1	117:6:33:1 115.9:1.9:38.6:0.6	9.696 (0.0235)‡
Purple vs. colorless inner glumes	3:1 and 27:37	47:76:16:18 49.7:68.1:16.5:22.7	2.051
Midseason vs. early	3:1 and 3:1	88:35:27:7 88.3:29.4:29.4:9.8	2.060
Cercospora resistant vs. susceptible with:			
Purple vs. colorless inner glumes	63:1 and 27:37	62:88:1:6 65.2:89.4:1.0:1.4	15.293 (2.036)‡
Midseason vs. early	63:1 and 3:1	112:38:3:4 115.9:38.6:1.9:0.6	20.044 (3.453)‡
Purple vs. colorless inglumes with:			
Midseason vs. early	27:37 and 3:1	45:18:70:24 49.7:16.5:68.1:22.7	0.707

*5% point is 7.815. †C.I. 3794×Delitus data; all other data from C.I. 3794×Fortuna.
‡Chi square is high due to poor fit for the ratio for Cercospora resistance. Figure in parenthesis is chi square for independence. 5% point is 3.841.

15 combinations for the cross C. I. 3794 × Fortuna, and 5 for the cross C. I. 3794 × Delitus. Observed and expected numbers are given for each combination on the basis of independent inheritance. When the same characters occurred in both crosses, the data for C. I. 3794 × Delitus are listed second under the respective combination.

Of the 20 ratio combinations, only those involving Cercospora resistance and susceptibility show significant deviations from the expected on the basis of independent inheritance as indicated by the Chi square test for goodness of fit. That this poor agreement is due to an excess of susceptible plants and not to linkage is shown by the Chi square test for independence as applied to resistance vs. susceptibility in relation to the other character pairs in the cross C. I. 3794 × Fortuna. These values are given in parenthesis in Table 3. In no instance did Chi square exceed the 5% point (3.841), thus indicating absence of linkage.

SUMMARY

Flower fragrance in rice was found in C. I. 3794, a variety introduced from the Philippines. Flower fragrance is characterized by a light but distinct sweet, somewhat violet-like odor at blooming time. It is distinct from the odor or flavor of scented rice grain and apparently does not occur in the grain. Fragrance in the crosses studied apparently is inherited as a single factor dominant, independent of pubescence, straw color, Cercospora resistance, purple color of inner glumes, purple color of outer glumes, and maturity. The latter characters were also inherited independently of one another.

LITERATURE CITED

1. ADAIR, C. ROY. Inheritance in rice of reaction to Helminthosporium oryzae and Cercospora oryzae. U.S.D.A. Tech. Bul. 772. 1941.
2. BREAUX, NORRIS. Character Inheritance, factor interaction, and linkage relations in the F_2 of a rice cross. Unpublished thesis, Louisiana State University. 1940.
3. CODD, L. E. W. Rice breeding, 1933–36. Agr. Jour. British Guiana, 7:115–128. 1936.
4. HEBERT, LEO P. A genetic study of color and certain other characters of rice. Unpublished thesis, Louisiana State University. 1938.
5. de la HOUSSAYE, D. A. Independent assortment, interaction of factors, and linkage studies in the F_2 of a rice cross. Proc. La. Acad. Sci., 6:52–59. 1942.
6. JODON, N. E., RYKER, T. C., and CHILTON, S. J. P. Inheritance of reaction to physiologic races of *Cercospora oryzae* in rice. Jour. Amer. Soc. Agron., 36:497–507. 1944.
7. JONES, J. W. Improvement in rice. U.S.D.A. Yearbook, 1936:415–454. 1936.
8. KADAM, B. S., and PATANKER, V. K. Inheritance of aroma in rice. Chron. Bot., 4:496–497. 1938.
9. MCLEAN, FORMAN T. A genetic analysis of the inheritance of fragrance of gladiolus. Bul. Torrey Bot. Club, 65:181–197. 1938.
10. RAMIAH, K. Scent in rice. Madras Agr. Jour., 25:173–176. 1937.
11. RYKER, T. C., and JODON, N. E. Inheritance of resistance of *Cercospora* oryzae in rice. Phytopath., 30:1041–1047. 1940.

A COMPARISON OF BROMEGRASS AND ORCHARD GRASS PASTURES[1]

R. F. Fuelleman, W. L. Burlison, and W. G. Kammlade[2]

THE value of a pasture species or mixture of species can be arrived at by purely agronomic methods, or through the medium of observing animals on pasture plus weight gains and losses. Either method is open to criticism, but when combined, they provide a fair measure of the productive ability of both vegetation and animals.

This paper presents data and observations obtained on pasture plots located on the Agronomy South Farm at Urbana, Ill.

METHODS AND PROCEDURE

The pasture plots on which this experiment was conducted are uniform with respect to soil and slope. Previous soil treatment was similar; the entire area was formerly treated as a unit in a standard corn belt rotation. Its use as pasture was dictated by a tendency to wash, although located on a slope of approximately 2%.

In the spring of 1938, 1/5- and 2/5-acre plots were seeded with alfalfa, *Medicago sativa;* smooth bromegrass, *Bromus inermis*, and alfalfa; bromegrass alone; orchard grass, *Dactylis glomerata*, and alfalfa; and orchard grass alone. The seeding rates per acre were as follows: Plot 1, 15 pounds of alfalfa; plot 2, 8 pounds of alfalfa and 12 pounds of bromegrass; plot 3, 15 pounds of bromegrass; plot 4, 8 pounds of alfalfa and 12 pounds of orchard grass; and plot 5, 15 pounds of orchard grass. Good stands were obtained on all plots. No further treatment was given to these plots in 1938.

In the spring of 1939, the plots were separated by fences. Water, salt, and shelters for animals were provided on each plot.

During this and each subsequent grazing season, yearling wether and ewe lambs were provided through the cooperation of the Animal Husbandry Department. The number of sheep grazed on each plot was calculated to give the best comparative results with respect to both vegetation and animals. The usual rate of stocking was 10 to 15 sheep to the acre. Animals were weighed at periodic intervals, usually once a month, or whenever a change in the number of sheep necessitated weighing.

Excepting 1939 and the short 1943 grazing season, the sheep were removed from plot 5 during August and September because of a lack of forage. This plan was followed in these experiments and the sheep were removed or added according to the amount of forage available.

Forage yields were obtained on each weigh day, using 4-foot square, steel cages to protect sampled areas. Sampling methods have been described in previous publications.[3] Dry matter was calculated from composite samples obtained on each sampling date. Composite samples for chemical analyses were obtained at the same time. These were subsequently analyzed for nitrogen, calcium, and phosphorus content. Botanical analyses were usually made either in the spring or fall or both, of each grazing season, using either hand separations or the vertical point quadrat method, depending upon forage height.

In the spring of 1942, the bromegrass plot was disked in an attempt to stimulate greater productivity.

Sheep were used as grazing animals in this experiment because a larger number

---

[1]Published by permission of the Director, Illinois Agricultural Experiment Station, Urbana, Ill. Received for publication July 15, 1944.

[2]Assistant Chief in Crop Production; Head, Department of Agronomy; and Professor of Animal Husbandry, respectively.

[3]Fuelleman, R. F., and Burlison, W. L. Pasture yields and consumption under grazing conditions. Jour. Amer. Soc. Agron., 31:5:399–412. 1939.

————, ————. A comparison of yields and composition of some Illinois pasture plants. Jour. Amer. Soc. Agron., 32:4:243–255. 1940.

of units could be used on small plots. Variation between animals is smaller than where larger animals are used and the danger of large errors due to uncontrollable factors is less. In addition, parasitic infestations, sometimes a serious factor influencing results, can be easily controlled in sheep.

In a given season the sheep used were uniform with respect to breed and initial live weights. Light weight lambs gain more weight than fat lambs and exaggerate forage fattening value to some extent. However, these gains are relative. Fat lambs following a period of grain feeding frequently failed to gain satisfactorily when turned onto pasture. This was particularly noticeable on pastures where orchard grass and bromegrass were seeded alone. Sheep made better gains on alfalfa or alfalfa-grass mixtures than on plots where no legumes were present.

SEASONAL WEATHER CONDITIONS

Seasonal weather conditions influence yield of forage and frequently the concurrent gains made by animals. In central Illinois the months of July, August, and part of September commonly have periods of low rainfall and high atmospheric humidity and temperatures. Total rainfall may be normal but poorly distributed. Although these factors are in part responsible for lowered yields of forage and animal gains, the forage species under consideration, particularly with respect to maturity and growth recovery, are obviously most seriously affected. Table 1 presents pertinent climatic data for the grazing seasons of 1939–43, inclusive.

TABLE 1.—*Climatic data for grazing seasons 1939–42, inclusive, with monthly totals of precipitation and mean air temperatures.*

Month	Year			
	1939	1940	1941	1942
Rainfall, Inches				
May	1.19	4.53	3.94	3.57
June	6.17	5.04	6.19	3.92
July	1.73	0.95	3.27	4.94
Aug	6.38	2.80	3.61	2.58
Sept	0.32	0.48	4.91	3.89
Oct	2.54	1.93	9.01	2.36
Mean Air Temperatures, °F				
May	65°	60°	66°	61°
June	76°	75°	73°	71°
July	76°	76°	75°	75°
Aug	72°	73°	74°	73°
Sept	72°	67°	69°	66°
Oct	57°	57°	59°	54°

RESULTS

FORAGE YIELDS AND ANALYSES

Largest acre yields of dry forage (Fig. 1) from all plots were obtained in 1939 and in 1941, the latter being a particularly favorable season for forage production. Consistently low yields were most marked on the orchard and bromegrass plots seeded alone (Table 2). An infestation of downy bromegrass, *Bromus tectorum*, in the latter plot necessitated mowing in May 1940. This early mowing and a "sod bound" condition caused a reduction in yield in subsequent

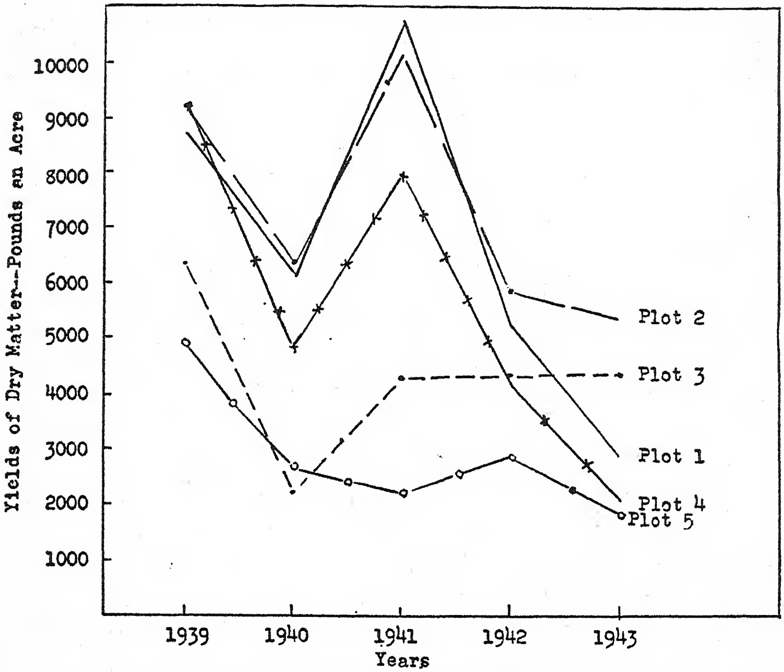


FIG. 1.—Yield of dry matter for 1939–43, inclusive.

grazing seasons. Orchard grass seeded alone, because of its early maturity, gave the lowest seasonal yields.

TABLE 2.—*Total acre yields in pounds of dry matter from pasture plots for the grazing seasons 1939–43, inclusive.*

Year	Kind of pasture				
	Plot 1, alfalfa	Plot 2, alfalfa-bromegrass	Plot 3, brome-grass	Plot 4, orchard grass-alfalfa	Plot 5, orchard grass
1939....	8,802	9,135	6,444	9,142	4,990
1940....	6,108	6,177	2,194	4,797	2,593
1941....	10,990	10,270	4,306	7,961	2,194
1942....	5,217†	5,964	4,434	4,204	2,849
1943*...	2,794†	5,458	4,464	2,046	1,896

*May to August. All plots plowed for new seedings in August.
†Kentucky bluegrass.

Evidence of the beneficial effect of alfalfa on yields is indicated in the greater amounts of forage produced where this legume was seeded with either orchard grass or bromegrass.

Bromegrass seeded alone (plot 3) was disked in the spring of 1941. This was done to overcome the depressing effect of a previous close clipping to destroy weeds. The effect of this disking was apparent in

the 1941 and 1942 yields when compared to yields in 1940 and was again apparent in 1943.

Orchard grass seeded alone (plot 5) was most productive in May and June, and it was during these months that sheep consumed it most readily. Although considerable mature top growth remained on this plot, it was necessary to remove the animals in late July to other pasture during most seasons. The low palatability of orchard grass after maturity seems to be a major factor in the utilization of orchard grass by sheep. If it is to be utilized to best advantage in the latitude of central Illinois, it should be pastured heavily during the months of May and June. With the advent of cool weather in late September and new growth, orchard grass again becomes palatable. Although it is more palatable at this season, the bunch type of growth when pastured closely leaves areas of unoccupied soil exposed. These areas are usually filled by annual crabgrass, *Digitaria* Sp., a species apparently unpalatable to sheep.

BOTANICAL ANALYSES

Botanical analyses of the vegetation (Fig. 2), made either by hand separations or the point quadrat method, indicated some interesting relationships between grazing and the time elapsed before alfalfa disappeared from the plots where seeded. Table 3 shows the percentages of alfalfa in plots 1, 2, and 4. Although bromegrass is considered

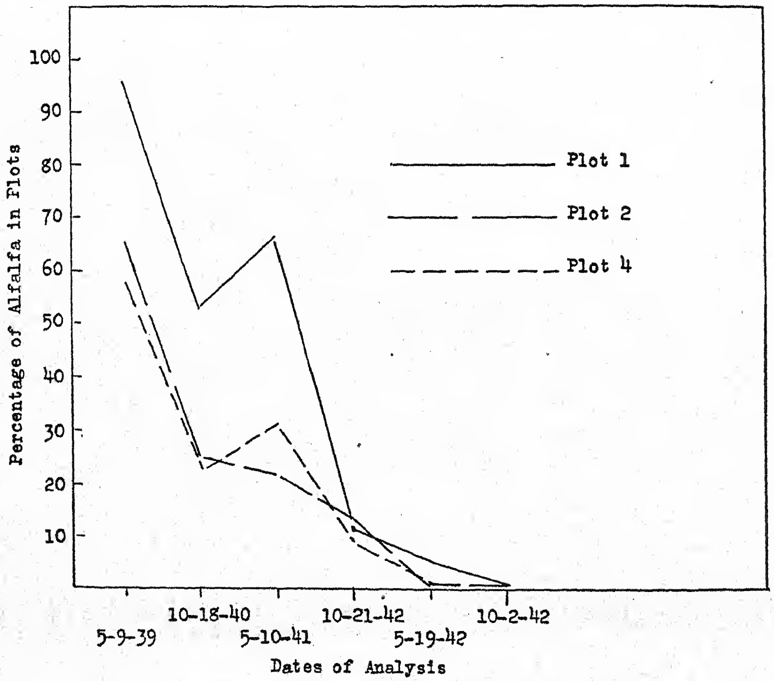


FIG. 2.— Percentage of alfalfa in plots on three sampling dates.

more palatable than orchard grass, similar percentages of alfalfa were present in plot 2 and in plot 4. This is explained on the basis of different types of growth. Bromegrass is more competitive than orchard grass as a result of its sod-forming type of growth. Orchard grass is a bunch type grass and offers less competition than bromegrass to associated species. The earlier maturity of orchard grass also favors associated species like alfalfa. In a favorable growing season such as 1941, the extremely vigorous growth of bromegrass tended to depress the growth of alfalfa.

TABLE 3.—*Percentages of alfalfa in pasture plots 1, 2, and 4.*

Date of analysis	Plot 1, alfalfa alone	Plot 2, bromegrass-alfalfa	Plot 4, alfalfa-orchard grass
May 9, 1939	96.1	65.5	57.6
Oct. 18, 1940	52.5	25.0	22.5
May 10, 1941	66.6	21.6	30.8
Oct. 21, 1941	11.5	12.5	9.5
May 19, 1942	5.0	Trace	Trace
Oct. 2, 1942	0.0	0.0	0.0

Percentages of grasses and other species on all plots, excluding alfalfa, are shown in Table 4. Some variability occurs from season to season. Where alfalfa was seeded alone, a vigorous growth of Kentucky bluegrass, *Poa pratensis*, occupied the plot by the spring of 1942. This indicates that close continuous grazing of alfalfa will markedly reduce the stand in 2 years and practically eliminate it by the end of the third year. Hence, grazing must be controlled if alfalfa stands are to last more than 2 years. The Kentucky bluegrass on plot 1 was exceptionally vigorous and luxuriant as a result of the preceding crop of alfalfa and favorable weather conditions.

TABLE 4.—*Percentages of grasses and other species excepting alfalfa in pasture plots during 1939–42, inclusive.**

Date of analysis	Plot No. 1		2		3		4		5	
	Kentucky bluegrass	Other species	Brome-grass	Other species	Brome-grass	Other species	Orchard grass	Other species	Orchard grass	Other species
May 9, 1939	1.9	0.0	34.5	0.0	91.4	8.6	42.4	0.0	94.7	5.3
Oct. 21, 1940	34.0	16.0	71.0	1.0	72.0	5.0	67.0	0.0	66.0	4.0
May 10, 1941	33.3	0.0	78.4	0.0	74.4	6.0	69.2	0.0	65.3	7.0
Oct. 21, 1941	48.5	37.5	74.0	6.0	73.0	11.5	83.5	0.5	63.5	31.0
May 19, 1942	75.0	18.0	73.0	2.0	70.0	8.0	79.0	0.0	64.0	21.0
Oct. 2, 1942	73.0	17.0	68.0	11.0	49.0	1.0	77.0	0.0	65.0	17.0

*Percentages of unoccupied space are not included. Other species refers to small percentages of orchard grass, white clover, redtop, and weeds.

Observations of the pastures during each grazing season showed that in the plots where alfalfa was seeded with bromegrass or orchard grass (plots 2 and 4), the grasses were darker green in color and more succulent than on plots where grasses were seeded alone. This was particularly true during the months of May and June. From a practical point of view the farmer would undoubtedly take advantage of this early spring growth period and utilize it to capacity for pasture. However, under experimental conditions, one of the factors under investigation was the response of the vegetation under a planned system of management.

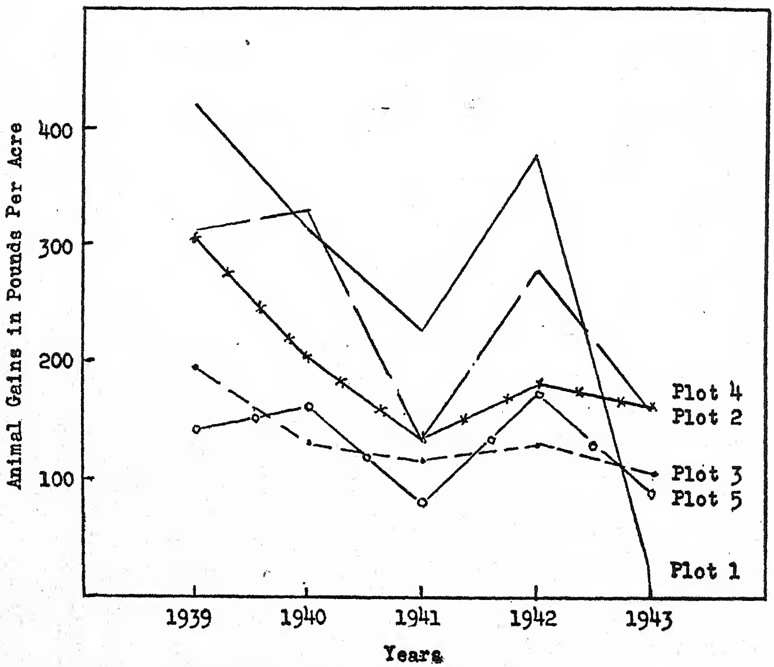


FIG. 3.— Animal gains on different pastures, 1939–43, inclusive.

GRAZING RESULTS

Animal gains and sheep pasture days supported the agronomic data and observations referred to previously. Pastures containing alfalfa not only yielded better, but also provided larger animals gains than grasses alone (Tables 5 and 6) in all seasons, except on plot 1 in 1943 when all of the alfalfa had been replaced by Kentucky bluegrass.

Animal gains were greatest in 1939, 1940, and 1942. The relatively low gains in 1941 and 1943 can be accounted for by the fact that the initial weights of the sheep used averaged approximately 85 pounds, a weight too high to allow for any large seasonal acre gains. Mature animals of the type used generally averaged from 100 to 110 pounds.[4]

[4]Texas fine wool, crossbred sheep.

Nevertheless, when the relative acre gains for all pastures in all seasons are considered, alfalfa alone and in mixture with grasses gave greater returns in both forage yields and animal gains than grasses alone (Fig 3).

Obviously, palatability of the different forages is a factor in weight gains by sheep. If they had been allowed to remain on the orchard grass (plot 5) through the entire grazing season, gains would in all probability have been small. Calculations attempting to assess the efficiency of the various forages as indicated by the pounds of gain per unit of forage produced are favorable to orchard grass in most seasons (Table 7). Efficiency as used here is based on the number of pounds of forage per acre available for consumption compared with the total animal gains in pounds per acre for a given season. The smaller the quantity of forage available for each pound of gain pro-

TABLE 5.—*Animal gains, sheep days, and dry matter yields per acre for grazing seasons, 1939–43, inclusive.**

Plot No.	Total animal gains, lbs. per acre	Total sheep pasture days an acre	Total dry matter yields, lbs. per acre
		1939	
1	420.0	1,620	8,802
2	311.0	1,620	9,135
3	194.0	1,620	6,444
4	302.5	1,620	9,142
5	145.0	1,370	4,990
		1940	
1	310.0	1,560	6,108
2	330.0	1,595	6,177
3	130.0	700	2,194
4	202.5	1,555	4,797
5	162.5	880	2,593
		1941	
1	225.0	1,820	10,990
2	127.5	2,130	10,270
3	117.5	1,520	4,306
4	127.5	1,820	7,961
5	76.5	620	2,194
		1942	
1	375.0	1,695	5,217
2	275.0	1,835	5,964
3	132.5	845	4,434
4	177.5	1,536	4,204
5	177.5	840	2,849
		1943*	
1	20.0	840	2,794
2	155.0	840	5,458
3	105.0	420	4,464
4	155.0	840	2,046
5	87.5*	476	1,896

*May to August.

duced, the greater the efficiency. When all factors are considered, a system of pasture management utilizing orchard grass during the forepart of the pasture season, followed by bromegrass, appears favorable for high seasonal production where both species are climatically and edaphically adapted.

TABLE 6.—*Total forage production and animal gains and average annual production and animal gains for seasons of 1939–43, inclusive.*

Plat No.	Pasture	Total 5-year forage production, lbs. per acre	Average annual production, lbs. per acre	Total number of pasture days per acre	Average annual number of pasture days per acre	Total 5-year animal gain, lbs. per acre	Average annual acre gain, lbs. per acre
1	Alfalfa	33,911	6,782	7,535	1,507	1,350	270
2	Brome-alfalfa	37,404	7,481	8,020	1,604	1,249	250
3	Bromegrass	21,842	4,368	4,105	821	679	136
4	Orchard grass-alfalfa	28,150	5,630	7,371	1,474	965	193
5	Orchard grass	14,522	2,904	4,186	837	649	130

TABLE 7.—*Relative efficiency of forages with calculations based on quantity of forage available for consumption per pound of animal gain.*

Plot No.	Pasture	Pounds of forage produced per pound of gain				
		1939	1940	1941	1942	1943
1	Alfalfa	20.9	19.7	48.8	13.9	—*
2	Alfalfa-bromegrass	29.4	18.4	80.5	21.7	37.7
3	Bromegrass	33.2	16.8	36.9	33.5	42.5
4	Alfalfa-orchard grass	30.2	23.6	62.4	23.7	13.2
5	Orchard grass	34.3	15.9	28.7	15.9	21.7

*Not calculated.

PROTEIN, CALCIUM, AND PHOSPHORUS CONTENT OF FORAGES

Although high protein content is generally associated with palatability and large gains in weight by sheep, it has been pointed out by Nevens[5] that succulence is of primary importance in dairy cattle forages to maintain and increase milk flow and live weight. Succulence and high protein content are characteristic of spring and early summer forages, and also of late fall growth under Illinois conditions. Table 8 shows the composition of forage samples for 1940, 1941, and 1942. Analyses are not complete for the 1942 season and only those for protein are included.

Another factor obviously influencing composition, particularly that of protein, is seasonal rainfall. In 1942 when the legumes formerly seeded in plots 1, 2, and 4 had disappeared, a rapid decline in the protein content of the remaining grasses occurred. During the seasons

[5]NEVENS, W. B. Results of experiments in improvement of pastures for dairy cattle. Trans. Ill. State Acad. Sci., 35:2. 1942.

TABLE 8.—*Chemical composition of forages at Urbana, Ill.*

Sampling date	Plot 1, alfalfa			Plot 2, alfalfa-bromegrass			Plot 3, bromegrass			Plot 4, alfalfa-orchard grass			Plot 5, Orchard grass		
	Protein, %	Ca, %	P, %	Protein, %	Ca, %	P, %	Protein, %	Ca, %	P, %	Protein, %	Ca, %	P, %	Protein, %	Ca, %	P, %
							1940								
May 3	24.44	1.28	0.376	17.94	0.841	0.360	14.19	0.337	0.298	18.69	0.949	0.351	16.81	0.423	0.368
June 1	20.75	1.22	0.431	19.81	0.896	0.386	11.56	0.272	0.190	17.38	0.623	0.365	8.56	0.194	0.371
June 17	23.13	1.22	0.441	23.56	1.05	4.75	16.88	0.341	0.353	14.50	0.494	0.444	—	—	—
July 6	22.00	1.12	0.335	14.63	0.559	0.342	—	—	—	14.13	0.864	0.367	6.81	0.346	0.301
Aug. 13	18.31	1.16	0.260	14.13	0.778	0.266	—	—	—	13.52	0.832	0.258	—	—	—
Sept. 19	17.19	0.681	0.209	20.56	1.39	0.237	11.69	0.793	0.245	19.00	1.12	0.236	10.19	0.552	0.351
Oct. 10	17.38	0.940	0.297	16.25	0.844	0.256	12.69	0.736	0.275	17.50	0.681	0.280	13.69	0.624	0.183
							1941								
May 5	22.38	1.01	3.92	16.25	0.660	0.355	14.38	0.309	0.327	17.69	0.682	0.367	13.00	0.277	0.350
May 15	—	—	—	13.75	0.253	0.339	12.31	0.270	0.296	13.75	0.203	0.324	9.88	0.264	0.286
June 5	20.69	1.15	0.362	12.56	0.465	0.310	10.69	0.338	0.491	11.19	0.382	0.372	9.13	0.324	0.437
July 8	19.00	0.981	0.330	13.75	0.730	0.288	11.81	0.386	0.296	14.63	0.648	0.481	—*	—*	—*
Sept. 3	15.81	0.962	0.286	18.63	0.490	0.230	10.75	0.456	0.311	13.63	0.588	0.408	—*	—*	—*
Oct. 2	20.19	0.832	0.311	17.56	0.597	0.386	17.81	0.454	0.372	16.81	0.480	0.368	—*	—*	—*
Nov. 4	16.00	0.635	0.281	12.75	0.471	0.288	15.25	0.432	0.359	14.25	0.438	0.381	14.25	0.770	0.382
							1942†								
May 2	17.25	—	—	15.31	—	—	13.18	—	—	13.31	—	—	15.29	—	—
June 1	10.26	—	—	8.81	—	—	9.11	—	—	6.88	—	—	8.56	—	—
June 30	10.94	—	—	7.63	—	—	7.38	—	—	8.50	—	—	7.81	—	—
July 28	11.31	—	—	9.13	—	—	6.81	—	—	9.25	—	—	9.50	—	—
Sept. 1	10.06	—	—	10.31	—	—	6.56	—	—	—	—	—	—	—	—
Sept. 29	—	—	—	10.31	—	—	10.06	—	—	11.06	—	—	11.56	—	—

*Not pastured.
†Air-dry samples.

of 1940 and 1941, the presence of alfalfa in plots 1, 2, and 4 apparently assisted in maintaining a relatively high protein content.

Percentages of calcium in samples from plot 1 (alfalfa) remained high during both seasons. Samples from grass-alfalfa mixtures, both plots 2 and 4, contained more calcium than those from plots 3 and 5 originally seeded to grasses alone.

CONCLUSIONS

Under imposed conditions of continuous moderately heavy grazing in central Illinois, alfalfa will not survive longer than 3 years. Stands decline rapidly during the second season and disappear by the end of the third season. To provide for a longer series of years of pasture, a system of alternate or light grazing is necessary. Where alfalfa is seeded with bromegrass or orchard grass and where other conditions are equal, alfalfa remains only for a slightly longer period in the bromegrass although bromegrass apparently approaches alfalfa in palatability. In alfalfa-orchard grass mixtures, the orchard grass being early maturing and less palatable during July and August is rejected in favor of the alfalfa, which consequently suffers because of the heavy grazing.

The association of legumes with grasses gives larger yields of forage as well as gains by animals, a factor of economic significance to livestock and dairy farmers. Protein and calcium content are materially increased both in percentages and pounds per acre production by including alfalfa in the mixture.

Orchard grass or bromegrass should not be seeded alone for pasture. Orchard grass, where adapted, is best utilized in mixtures. In some cases a seeding of orchard grass alone can be used to advantage as an early pasture, where an alternate field or fields of other species are provided for summer and early fall grazing. Both bromegrass and orchard grass give larger yields where associated with a legume such as alfalfa. The effect of the legume on yields of bromegrass is shown in Table 2 in the data for plot 2. Although the alfalfa had disappeared from this plot in 1942 (Table 3), forage yields were higher in 1942 and 1943 than from plot 3 seeded with bromegrass alone.

SUMMARY

Seedings of alfalfa alone and with bromegrass and orchard grass and of orchard grass and bromegrass seeded alone were made in 1938. All came up to good stands.

Comparative forage production over a period of 5 years showed that largest yields were obtained on pastures containing alfalfa. Likewise, animal gains per acre were greater on these pastures. Grasses seeded alone produced approximately 40% less forage and 50% smaller gains in live weight.

Chemical analyses indicated a very favorable increase in protein and calcium content of the mixtures where alfalfa was seeded with either bromegrass or orchard grass.

THE EFFECT OF CLODDINESS OF SOILS ON THEIR SUSCEPTIBILITY TO WIND EROSION[1]

C. E. Van Doren[2]

SIEVING tests of the surface inch of soil to determine the percentage of various sizes of clods and soil particles have been in progress at the Amarillo Conservation Experiment Station for the past 2 years. The purpose of this study is to determine the susceptibility of soils to wind action in order to predict the probability of wind erosion and to make comparisons of the breaking down or building up of clods through the season. Changes in cloddiness may be caused by several factors, such as climatic conditions, type of tillage and seeding implement used, condition of soil at time of tillage or seeding, kind of crop grown, and amount of residue on the surface or mixed in the surface soil. Clod stability and size distribution are important factors determining resistance of land to wind action.

FIELD SAMPLING METHOD

Field samples for cloddiness analyses were taken with a common flat spade, well sharpened to facilitate ease of sampling, following the technic of Metzger and Hide.[3] The spade was inserted approximately 1 inch in depth and a spadeful taken at that depth at four different locations over any particular condition that was sampled. All four samples were placed together in one paper sack and allowed to air dry before sieving. Care was exercised to prevent any further breakage of clods by handling. If residue was present on the ground surface or mixed in the soil, it was taken with the sample and separated at time of sieving.

Sieving equipment.—The sieves used had openings of 2, 1, ½, and ¼ inches, and 2.38, 0.84, and 0.177 mm. The first four sieves were constructed of lumber and were made 12 inches square with hail screen of the size openings indicated fastened to the bottom of each one. The three smaller sieves given in millimeter sizes are regular U. S. standard sieves Nos. 8, 20, and 80.

Precedure.—The procedure followed in running the samples through the sieves was as follows: After the sample had been air-dried, it was first run through the 12-inch square sieves. The sample was placed in the top sieve and the entire nest of sieves and the pan picked up and shaken gently two or three times to get the smaller particles of soil down on the lower sieves. The larger clods that should pass the top screen were then worked through by hand, care being used to avoid unnecessary breakage, and those larger than 2 inches removed and weighed. This procedure was repeated for the 1-inch sieve. After the top two sieves had been removed, the remaining two were shaken gently before the ½-inch sieve was removed. The ¼-inch sieve alone was then shaken two or three times. All of the fractions were weighed. The soil passing through the four larger sieves into the pan was then run through the three U. S. standard sieves individually and each size of particles weighed. The soil was run through these sieves gently without vigorous shaking so that soil particles were not ground off to smaller sizes. The soil passing through the last sieve was also weighed and classed as particles less

[1]Contribution from the Amarillo Conservation Experiment Station, Soil Conservation Service, Amarillo, Texas, in cooperation with the Texas Agricultural Experiment Station. Received for publication July 15, 1944.

[2]Assistant Conservationist. Acknowledgement is hereby made to Luther K. Eby, formerly of this station, who carried on preliminary studies on this project, and to Charles J. Whitfield for assistance in the present work.

[3]Metzger, W. H., and Hide, J. C. Effect of certain crops and soil treatments on soil aggregation and the distribution of organic carbon in relation to aggregate size. Jour. Amer. Soc. Agron., 30:833–843. 1938.

than 0.177 mm in size. After all size particles had been weighed, the percentage of each was figured from the total weight of the sample.

RESULTS OF SIEVING TESTS

This method of running sieve analyses of the surface soil of Pullman clay loam was first used extensively in January and February 1942. Results of preliminary tests run previous to that time indicated that particles of soil about 2 mm or less in size were the critical size particles from the standpoint of movement by wind action. Data secured during the past 2 years verify this fact. It was determined by field observations and measurements of wind speed at the ground level that a speed of from 12 to 15 miles per hour will start soil movement on unprotected land free of crop residues or growing crops if the percentage of soil particles 2 mm or less in size is high. During the past 2 years, samples have been taken just prior to and during the blow season. From samples taken on areas just prior to the time soil movement actually took place, the percentage of particles 2 mm and less in size must be about 65% or above before soil movement will start. In other words, any piece of land of the heavy type soils, such as Pullman clay loam, that is free of crop residues or growing crops is vulnerable to wind erosion when the percentage of soil particles 2 mm or less in size is 65% or above and the wind speed reaches velocities of from 12 to 15 miles per hour at the ground level. During the blow season in the winter and early spring, the wind often reaches this speed close to the ground level; hence, the necessity of some form of protection to farm land during the critical blow period. The data secured show that in many instances the soil is in a condition to blow but has sufficient crop residues or growing crops to prevent soil movement.

Tables 1 and 2 give the percentage of the various size soil particles on areas where soil movement took place during the winter and early spring of 1942, 1943, and 1944.

TABLE 1.—*Percentage of clod size on areas where wind erosion occurred.*

Treatment	Percentage of various size clods							
	2 in.	1 in.	½ in.	¼ in.	2.38 mm	0.84 mm	0.177 mm	Less than 0.177 mm
Clean fallow, listed	0	1.4	6.3	8.4	9.3	24.6	35.2	14.8
Clean fallow, sorghum failure	0	2.6	9.1	10.2	9.2	16.9	37.1	14.9
Lake bottom, no treatment	0	5.7	10.8	8.9	6.4	13.8	46.7	7.7
Gullies from water erosion	0	0.0	1.0	2.4	5.1	19.1	51.6	20.7
Terrace ridges, seeded to wheat	0	4.9	8.5	11.3	14.3	27.5	24.2	9.3

Table 1 shows the percentage distribution of clod size from less than 0.177 mm to 2 inches and above. Table 2 separates the clods into two catagories, the erodible aggregates and the nonerodible ag-

TABLE 2.—*Percentage of erodible and nonerodible aggregates on areas where wind erosion occurred.*

Treatment	Percentage of clod size	
	2.38 mm and above	Less than 2.38 mm
Clean fallow, listed fall of 1941......	25.4	74.6
Clean fallow, sorghum failure........	31.1	68.9
Lake bottom, no treatment..........	31.8	68.2
Gullies, from water erosion..........	8.5	91.5
Terrace ridges, seeded to wheat......	39.0	61.0

gregates, as determined by this analysis. The terrace ridges started blowing when the percentage of erodible particles was below 65%. The terraces were high and the wind hit them with greater force than it would have had they been at the normal ground level. When wind speed is from 12 to 15 miles per hour at the ground level, it is often 25 to 30 miles per hour 2½ feet from the ground, which explains the greater susceptibility of terrace ridges.

Tables 3 and 4 show the clod distribution on a number of varied conditions that existed on the station in January and February 1942 where no erosion took place.

TABLE 3.—*Percentage of clod size on areas with no wind erosion.*

Treatment	Percentage of various size clods							
	2 in.	1 in.	½ in.	¼ in.	2.38 mm	0.84 mm	0.177 mm	Less than 0.177 mm
Wheat after wheat, drilled before heavy fall rains.......	5.6	16.0	16.3	12.0	9.5	13.1	18.4	9.1
Wheat after wheat, drilled after heavy fall rains..........	2.1	7.7	11.3	10.9	8.7	15.3	33.5	10.5
Wheat on fallow, drilled before heavy fall rains...........	31.9	14.6	12.0	9.5	6.1	7.2	11.0	7.7
Wheat on fallow, drilled after heavy fall rains...........	4.6	11.0	14.1	11.4	9.1	12.7	26.1	11.0
Fallow-listed, Jan. 1942......	27.5	16.4	13.7	9.2	7.9	11.0	11.4	2.9
Volunteer wheat............	0.3	9.9	11.4	8.9	7.1	14.0	34.0	14.3
Sorghum stubble, undisturbed	0.5	4.1	9.1	7.8	6.8	15.4	43.9	12.4
Weed cover, undisturbed....	0.5	3.1	8.5	7.3	5.5	11.4	48.5	15.2
Continuous wheat plots......	18.0	8.5	13.1	8.5	7.5	11.5	23.7	9.3
Continuous sorghum plots....	19.7	19.1	13.9	9.5	5.4	9.3	14.0	9.1
Grass, reseeded, 1941........	0	7.4	16.0	14.2	11.0	16.5	28.3	6.7

The great differences in soil condition in the winter of 1942 are shown in Tables 3 and 4. In October 1941 an exceptionally large amount of precipitation was received (9.14 inches). A great part of this precipitation came at a high intensity which packed the surface soil where it was not protected by crop residues. Undisturbed sorghum

and weed cover had the highest percentage of soil aggregates 2 mm or less in size, but these areas did not blow because of the protective cover of sorghum stubble and weeds. The percentage was low on the continuous sorghum and continuous wheat plots because water stood for some time on the plot and as a result the surface was heavily crusted. Quite a difference is noted on the area seeded to wheat before and after the heavy October rains. The fallow plot that was listed in January 1942 was very cloddy, as indicated by the low percentage of small clods as shown in Table 4.

TABLE 4.—*Percentage of erodible aggregates on areas with no wind erosion.*

Treatment	Percentage clod size 2 mm and less
Wheat after wheat, drilled before heavy fall rains	40.6
Wheat after wheat, drilled after heavy fall rains	59.3
Wheat on fallow, drilled before heavy fall rains	25.9
Wheat on fallow, drilled after heavy fall rains	49.8
Fallow, listed Jan. 1942	25.3
Volunteer wheat	62.3
Sorghum stubble cover, undisturbed	71.7
Weed cover, undisturbed	75.1
Continuous wheat plots	44.5
Continuous sorghum plots	32.4
Grass, reseeded 1941	51.5

During the 1943 season, samples were taken at two different periods, one set in February and the other in November at the close of the growing season. The results of these two samplings show the change in clod structure through the season. Table 5 gives the results of the two samplings.

TABLE 5.—*Comparison of clod distribution at two different dates in 1943.*

Size of clods	Percentage of various size clods											
	Continuous wheat, 1943		Continuous sorghum, 1943		Wheat on fallow, 1943		Sorghum after wheat, 1943		Fallow after sorghum, 1943		Stubble mulch fallow, 1943	
	Feb.	Nov.	Feb.	Nov.	Feb.	Nov.	Feb.	Nov.	Feb.	Nov.	Feb.	Nov.
2 in.	0	4.9	5.6	0	0	3.8	0	0	0	10.8	6.4	3.4
1 in.	4.8	8.8	12.1	8.2	6.2	8.0	10.3	5.3	5.6	5.8	16.2	9.9
½ in.	8.9	14.8	15.0	16.0	11.2	18.4	15.4	8.4	9.3	9.2	12.3	14.3
¼ in.	9.5	12.8	9.5	13.7	13.6	11.8	10.7	9.4	10.4	11.7	10.1	11.9
2.38 mm.	9.3	10.6	8.5	11.0	9.7	9.7	9.7	10.6	8.5	9.3	7.4	8.9
0.84 mm.	17.0	13.5	10.6	13.1	17.6	16.0	15.2	16.0	16.0	11.7	10.6	11.8
0.177 mm.	36.6	19.8	25.9	20.9	32.2	22.5	30.9	30.7	40.9	25.3	25.7	23.5
Less than 0.177 mm.	14.0	14.9	12.8	17.1	9.5	9.9	7.8	19.5	9.4	16.3	11.2	16.4

The greatest change occurred in the percentage of clods from ½ to 2 inches in size and those 0.177 mm and less in size. The soil ag-

gregates ranging from 0.84 mm to ¼ inch seem to remain more uniform in amount regardless of treatment. Continuous wheat, wheat on fallow, and fallow after sorghum show an increase of larger clods and a decrease in the amount of smaller clods during the period from February to November. Continuous sorghum, sorghum after wheat, and stubble mulch fallow show the opposite effect. Cultivation of sorghum during the summer tends to break down clod formations, while cultivation of wheat land during the same period forms larger clods because of the compactness of the soil which is usually dry at harvest time. Sorghum land is usually left undisturbed after harvest in the fall, leaving a stubble cover for protection from wind erosion. Tillage and seeding operations on wheat land in the fall leave the land in a much different condition and more vulnerable to wind erosion unless a good cover of wheat develops or a protective residue is left on the surface by stubble mulch tillage. The greatest natural breakdown of clods seems to occur during the winter months when the land is not disturbed by cultivation and is subject to weathering from alternate freezing and thawing. During this time, there are usually numerous small snows accompanied by high winds which have a tendency to sift along the ground surface and add to the disintegration of clod formations; thus, the necessity of planning a good land management for maximum protection during the winter and spring blow season.

An example of how this type of information can be used for determining susceptibility of soils to wind action can be shown from the data secured in 1942. Samples were taken the first part of February and again the last of March on areas representing conditions existing on the station. In February, the two clean fallow plots in the rotation series (wheat, sorghum, fallow, and grass) showed the soil aggregates 2 mm and less to be 63.6%. The samples taken in March, just 2 days before the plots started blowing, showed an increase up to 64.6%. Results of the first sampling indicated that the two plots were likely to blow since there was no protective crop residue. The second sampling showed that there had been additional breaking down of clods. Damaging winds were received in February but no erosion took place until the heavy wind the last of March. Table 6 shows the change in clod structure on the fallow plots.

TABLE 6.—*Comparison of clod distribution on clean fallow plots.*

Date sampled	Percentage of various size clods							
	2 in.	1 in.	½ in.	¼ in.	2.38 mm	0.84 mm	0.177 mm	Less than 0.177 mm
Feb. 1942	0	4.2	11.8	10.9	9.8	20.9	30.7	12.0
Mar. 1942	0	1.4	6.3	8.4	9.3	24.6	35.2	14.8

These figures show a significant reduction in the percentage of clods ¼ inch and larger and an increase in percentage of smaller clods.

DISCUSSION AND SUMMARY

Since the percentage of soil aggregates, approximately 2 mm or less in size, as determined by this method, is the critical point determining the susceptibility of soils to wind action at the ground velocities normally encountered, the process of sieving could be reduced to one sieving to separate the two categories of clod size. This would greatly reduce the amount of time and labor needed to sieve the samples, making it possible to run a great many more samples.

The complete sieving can be used where a study of detailed change in clod structure is desired.

Analyses of clod structure carried out before and after tillage and seeding operations throughout the season gives a good evaluation of the effect of the various tillage and seeding implements on clod structure.

These studies have a practical application in providing a means whereby the susceptibility of land to wind erosion can be determined in advance of the blow season and measures taken to prevent wind erosion. Usually much less damage is done to the land and crop where blowing is prevented rather than where emergency measures are taken after blowing has started.

EFFECT OF BORON CONCENTRATION IN THE NUTRIENT SOLUTION ON THE SOLUBLE AND INSOLUBLE NITROGEN FRACTIONS OF SPINACH[1]

P. N. SCRIPTURE AND J. S. MCHARGUE[2]

SOME published findings suggest that boron has an important function in the metabolism of nitrogen in plants (1, 2, 6, 8).[3] This experiment was made to obtain additional information on that subject.

PLAN OF THE EXPERIMENT

Spinach (variety Bloomsdale) was grown in sand cultures using the continuous-drip method of Shive and Robbins (7) to supply the nutrients. Two-gallon, glazed earthenware jars were filled with purified sand in which 10 to 15 spinach seeds were planted. The continuous-drip apparatus was set up and the sand kept moist with distilled water until the seed germinated. When the first true leaves were forming the seedlings were thinned to five of uniform size and vigor in each jar. The application of the nutrient solution with varying amounts of boron was started at this time. The basic nutrient solution used had the following composition: KH_2PO_4, 0.0015 molar; $MgSO_4.7\,H_2O$, 0.0022 molar, and Ca $(NO_3)_2.\,4H_2O$, 0.0022 molar. Zinc and manganese were included as sulfates at the rate of 1 p.p.m. each of the elements. Iron was supplied as $FeSO_4(NH_4)_2SO_4.6H_2O$ in amounts necessary to prevent chlorosis. It was found necessary to increase the iron application slightly during long periods of bright weather. Boron was supplied as boric acid (H_3BO_3) in concentrations as follows:

Jar Nos.	Boron in nutrient solution, p.p.m.
1 & 2	0.25
3 & 4	0.50
5 & 6	1.00
7 & 8	5.00

Each culture jar received approximately 1 liter of nutrient solution every 24 hours throughout the growth period. Excess salts were washed out by flushing the the sand with distilled water twice weekly.

All cultures made rapid and uniform growth during the first 2 weeks after the nutrient treatments were started. At this time the cultures receiving only 0.25 p.p.m. of boron were observed to be growing less rapidly than the others. No evidence of a deficiency was noticed, however. At this time a few of the older leaves of the plants receiving 5.00 p.p.m. of boron showed a slight browning of the tips which indicated toxicity, but they soon recovered and continued to make good growth. The plants were sampled 64 days after planting. At this time definite symptoms of boron deficiency were noticeable on the cultures receiving only 0.25 p.p.m. of boron. The terminal leaves were a darker green than the corresponding leaves on plants receiving more boron and they had a glossy appearance. The leaf surfaces were rougher than normal and they curled inward toward the midrib.

SAMPLING

Sampling was done on a clear day and was begun at 10:00 a.m. The plants were cut off at the surface of the sand; those from each culture constituted a sample.

[1]Contribution from the Department of Chemistry of the Kentucky Agricultural Experiment Station, Lexington, Ky. The investigation reported in this paper is in connection with a project of the Kentucky Agricultural Experiment Station and is published by permission of the Director. Received for publication July 24, 1944.

[2]Assistant Chemist and Head of Department, respectively.

[3]Figures in parenthesis refer to "Literature Cited", p. 869.

The plant tissue was brought to the laboratory at once and the leaf blades and petioles separated. Each portion was chopped fine and placed in a weighed Erlenmeyer flask. The green weight of each sample was taken as rapidly as possible and then the plant tissue was covered with boiling 95% ethyl alcohol. The flasks were loosely stoppered and heated on the steam bath until the alcohol had boiled moderately for ½ hour. After standing at room temperature for 24 hours, the extract was decanted through a filter paper into a volumetric flask. The residue was treated with 50% alcohol and boiled on the steam bath for 15 minutes. After standing as before the extract was decanted into the respective volumetric flasks. The extraction with 50% alcohol was repeated six times after which it was assumed that all soluble nitrogen was removed. The residues were transferred to the filter and washed thoroughly with 50% alcohol. The extracts were made to volume with alcohol and the residue on the filter transferred to weighed beakers, dried overnight at 100° C, and the weights determined. The residues were then ground to pass an 80-mesh sieve and stored in tightly stoppered bottles.

CHEMICAL ANALYSIS OF THE EXTRACT

TOTAL SOLIDS SOLUBLE IN 50% ALCOHOL

Ten ml of the extract were measured into a tared 50-ml beaker, carefully evaporated to dryness on the steam bath, and then dried to constant weight in a vacuum oven at a temperature of 58° C. The total weight of soluble material in the sample was calculated and this weight plus the weight of the insoluble residue constitutes the total dry weight of the sample.

TOTAL NITROGEN

Since the extracts contained nitrate, it was necessary to use a method to include it. Accordingly, the reduced-iron method of Pucher, *et al.* (5) was used. It was adapted to a micro-scale using 10 ml of the alcoholic extract. Metallic selenium was used as a catalyst instead of copper sulfate which shortened the time of digestion. Distillations were made with the Kirk micro-distillation apparatus (3).

ANALYSIS OF THE INSOLUBLE RESIDUE

Total nitrogen: Total nitrogen was determined on a 0.05-gram sample, using a regular Kjeldahl micro procedure. Selenium was used as a catalyst.

RESULTS

The total yields of fresh plant material produced on each culture jar show some differences due to the variation in boron content of the nutrient solution. These results are presented in Table 1.

TABLE 1.—*Yield in grams of fresh spinach.*

Boron added in p.p.m.	Yield per jar, grams	Mean of duplicate cultures, grams
0.25 0.25	35.20 35.00	35.10
0.50 0.50	42.45 41.75	42.10
1.00 1.00	56.10 56.50	56.30
5.00 5.00	38.70 50.65	44.68

The soluble nitrogen content of the leaf blades and petioles is given in Table 2. The results are expressed as percentages on a dry-weight basis.

TABLE 2.—*Soluble nitrogen content of leaf blades and petioles.*

Boron added, p.p.m.	Soluble N, %	Mean N of duplicate cultures, %
	Leaf Blades	
0.25 0.25	1.849 2.349	2.099
0.50 0.50	2.143 2.376	2.259
1.00 1.00	1.670 2.300	1.985
5.00 5.00	1.767 1.710	1.738
	Petioles	
0.25 0.25	2.394 3.319	2.856
0.50 0.50	2.531 2.949	2.740
1.00 1.00	2.944 3.626	3.285
5.00 5.00	2.572 2.978	2.775

The insoluble nitrogen content of the leaf blades and petioles is given in Table 3. The results are given as percentages on a dry-weight basis.

DISCUSSION

From Table 1 it can be seen that the amount of boron in the nutrient solution had considerable effect on the yield of spinach. Apparently, a concentration of 1 p.p.m. is the optimum for maximum yield.

The results obtained for the percentages of alcohol-soluble and alcohol-insoluble or protein nitrogen are given in Tables 2 and 3. With respect to the leaf blades, it appears that as the boron concentration of the nutrient solution is increased more nitrogen is synthesized to protein. The differences are not large, but the trend over the range of boron concentrations used is probably significant. This is in agreement with the work of Briggs (2), who found that the rate of protein synthesis increased even when toxic quantities of boron were present.

The boron concentration apparently had little effect on the amounts of soluble and insoluble nitrogen in the petioles.

TABLE 3.—*Insoluble nitrogen content of leaf blades and petioles.*

Boron added, p.p.m.	Insoluble N, %	Mean N of duplicate cultures, %
	Leaf Blades	
0.25 0.25	3.764 3.302	3.533
0.50 0.50	3.686 3.838	3.762
1.00 1.00	4.110 3.866	3.988
5.00 5.00	4.020 3.984	4.002
	Petioles	
0.25 0.25	1.858 1.790	1.824
0.50 0.50	1.763 1.933	1.848
1.00 1.00	1.165 1.496	1.330
5.00 5.00	1.869 1.359	1.614

It seems possible that boron has a definite function in the formation of proteins from inorganic nitrogen and carbohydrates. Several workers (6, 8) have found that in severe stages of boron deficiency, large amounts of soluble inorganic and organic nitrogen and simple sugars accumulate simultaneously in the plant cells. While some of the nitrogen compounds doubtless are derived from proteolysis which takes place in dead or dying leaves, it would seem that part of the accumulation is due to an arresting of amino acid and protein synthesis because of a lack of boron. Proteins are required in large amounts for building new protoplasm in the growing tips of plants. The visible symptoms of boron deficiency indicate an excess of carbohydrate and a shortage of protein in the meristematic regions of the plant since this condition always causes thick-walled cells with little protoplasm formed (4); and, in turn, the thickening and stiffening of the terminal leaves and stems and the light green or yellow color so characteristic of the advanced stages of boron deficiency.

SUMMARY

1. Spinach plants were grown in sand cultures with boron supplied in the nutrient solution at the following rates: 0.25, 0.50, 1.00, and 5.00 p.p.m.

2. The soluble nitrogen was extracted from the fresh plant material with 50% ethyl alcohol and the percentages of soluble and insoluble or protein nitrogen determined.

3. As the boron concentration of the nutrient solution was increased, the rate of protein synthesis tended to increase.

LITERATURE CITED

1. BECKENBACH, J. R. Functional relationships between boron and various ions in the nutrition of the tomato. Fla. Agr. Exp. Sta. Bul. 395. 1944.
2. BRIGGS, G. B. Effect of boron in the substrate on the rate of nitrate absorption and on distribution in nasturtium. Plant Phys., 18:415–432. 1943.
3. Kirk, P. L. A one-piece glass micro-Kjeldahl distillation apparatus. Ind. and Eng. Chem., Anal. Ed., 8:223–224. 1936.
4. KRAUS, E. J., and KRAYBILL, H. R. Vegetation and reproduction with special reference to the tomato. Ore. Agr. Exp. Sta. Bul. 149. 1918.
5. PUCHER, G. W., LEAVENWORTH, C. S., and VICKERY, H. B. Total nitrogen in plant extracts in presence of nitrates. Ind. and Eng. Chem., Anal. Ed., 2:191–192. 1930.
6. SCRIPTURE, P. N., and MCHARGUE, J. S. Effect of boron deficiency on the soluble nitrogen and carbohydrate content of alfalfa. Jour. Amer. Soc. Agron., 35:988-992. 1943.
7. SHIVE, J. W., and ROBBINS, W. R. Methods of growing plants in solution and sand culture. N. J. Agr. Exp. Sta. Bul. 636. 1940.
8. WADLEIGH, C. H., and SHIVE, J. W. A microchemical study of the effects of boron deficiency in cotton seedlings. Soil. Sci., 47:33–36. 1939.

NOTES

FIELD OBSERVATION REGARDING THE VALUE OF ROOT NODULE BACTERIA[1]

THE beneficial effect of the association of root nodule bacteria with the Leguminosae has been well established. The following situation was observed during the 1944 season in a field of alfalfa located on the College Farm of the University of Delaware, Newark, Del. The alfalfa was seeded in August, 1943, on a Sassafras sandy loam which had been adequately limed and fertilized with 400 to 500 pounds of 3–10–10 per acre. The seed was inoculated with a commercial culture. Extremely dry weather persisted and germination was delayed for approximately 4 weeks. As growth progressed in the spring of 1944, it was noted that in rather large areas over the field the plants were yellow and stunted. In other localized spots the plants were green and appeared to be normal. An examination of the roots showed that no nodules were present on the stunted plants but were prevalent on the normal plants (Figs. 1 and 2).

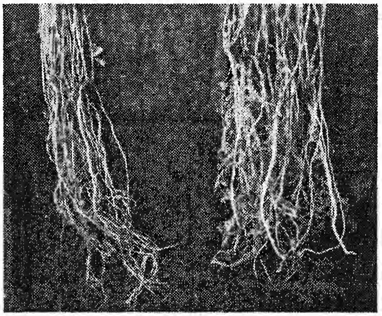


FIG. 1.—*Left*, roots from alfalfa plants with no nodules; *right*, roots from alfalfa plants with nodules.

[1]Contribution from the Department of Agronomy, University of Delaware, Newark, Del. Published with the permission of the Director of the Agricultural Experiment Station.

As a result of this observation the following fertilizers at the rate of 300 pounds per acre were applied broadcast to plots in one of these typical areas of yellow and stunted plants: 0-14-0, 0-0-14, 0-14-14, 14-0-0, and 14-14-14. The plots were harvested June 3 and the following yields per acre secured:

Fertilizer treatment	Pounds per acre of air-dry hay
14-14-14	2,820
14-0-0	2,460
0-14-14	1,620
0-14-0	1,480
0-0-14	1,540
No fertilizer	1,560
Difference required for significance	338

Obviously the nitrogen alone was responsible for the greatest increase in growth. The plots on which the 14-14-14 fertilizer was applied gave a significant increase in yield over the plots receiving nitrogen, but with all other treatments no significant gain over the yield of the check plots was obtained. The fact that these increases in yield were obtained in 29 days further substantiates the role of the nitrogen as the causal agent. (See Fig. 3.)

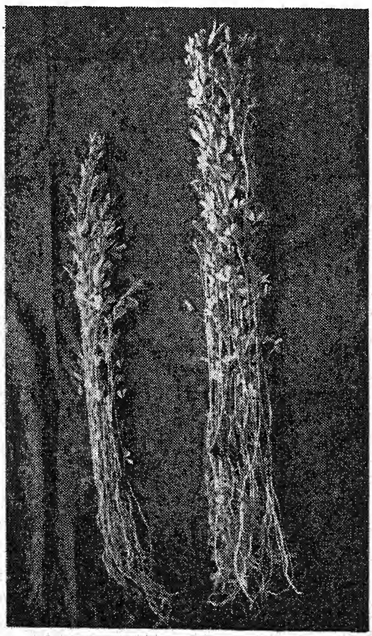


FIG. 2.—Comparative size of alfalfa plants without nodules (*left*) and with nodules (*right*).

At the time of harvest (June 3) the tops and roots of a number of stunted plants and of the normal plants were harvested, the roots carefully washed and dried, and the percentage of nitrogen contained in the tops and roots determined (Table 1).

These data show that the ratio of tops to roots in plants well nodulated to be 2.9 as compared with 2.0 for plants with no nodules. An increase of 1% in nitrogen content of the tops and 1.26% in the roots can be ascribed to the root nodule bacteria.

From these data and based on the assumption that the yield of plants well nodulated was equal to the average yield of plants grown on plots receiving nitrogen fertilizer, it was estimated that under the existing conditions the root nodule bacteria were responsible for fixing approximately 67 pounds of nitrogen per acre until June 3.

This figure, as in all cases of estimating the amount of nitrogen

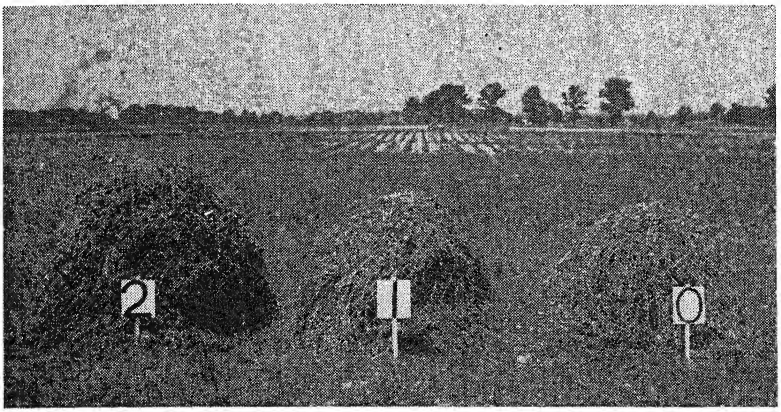


FIG. 3.—The effect of nitrogen on yield of alfalfa without nodules over a 29-day period. 0, no fertilizer, yield 1,560 pounds per acre; 1, 300 pounds of 0–14–14 per acre, yield, 1,620 pounds per acre; 2, 300 pounds of 14–0–0 per acre, yield 2,460 pounds per acre.

TABLE 1.—*Comparison of nodulated and unnodulated plants.*

	Average weight of top per plant, grams	Average weight of root per plant, grams	N in tops, %	N in roots, %
Plants with nodules...	0.810	0.279	3.27	2.14
Plants without nodules	0.370	0.185	2.27	0.88

fixed by root nodule bacteria, is only an approximation. Although, the estimates are based on both tops and roots of the plant, certain inherent errors in the method are present, among which are the factors of the difficulty of accounting for all the roots, the inability to determine the amount of nitrogen of the roots given off to the soil by decay or excretion, and the assumption that nodule-bearing leguminous plants assimilate nitrogen from the soil at the same rate as plants without nodules.

A possible explanation for the lack of nodules on the alfalfa plants although the seed was inoculated is that the long dry period prevailing after the seed was planted prevented the bacteria from becoming established.—JOHN F. DAVIS, *Department of Agronomy, Delaware Agricultural Experiment Station, Newark, Del.*

A SUGAR BEET TRANSPLANTING MACHINE

IN sugar beet breeding work it is common practice to produce the initial seed crop by the biennial method, whereby the beets are grown one season, stored over winter, and transplanted to the field the second season. Where the number of beets involved is small, the transplanting is usually done by hand. However, where several hundred beets or more are involved in a given planting, a transplanting machine would be desirable, particularly during the present shortage of labor.

In view of the labor shortage at Sheridan, Wyo., in the spring of 1944, the machine illustrated in Fig. 1 was built and successfully used to transplant 45 plantings varying in size from 0.1 to 0.5 acre. Fig. 1B shows the base of the machine, which is 4 feet wide by 6 feet in length, with the furrow openers attached on 40 inch centers. Fig. 1A shows the side view of the transplanter and the tractor hitch. The 5-foot width upper deck is elevated 12 inches and covered with a mattress. The supply box is fastened to the base and extends to the rear. Empty storage crates or extra beets may be carried on the upper deck.

Fig. 1C shows the machine in operation and the method of transplanting. Two 40-inch rows are planted each trip through the field. The furrow openers form deep furrows and the twisted arms pull

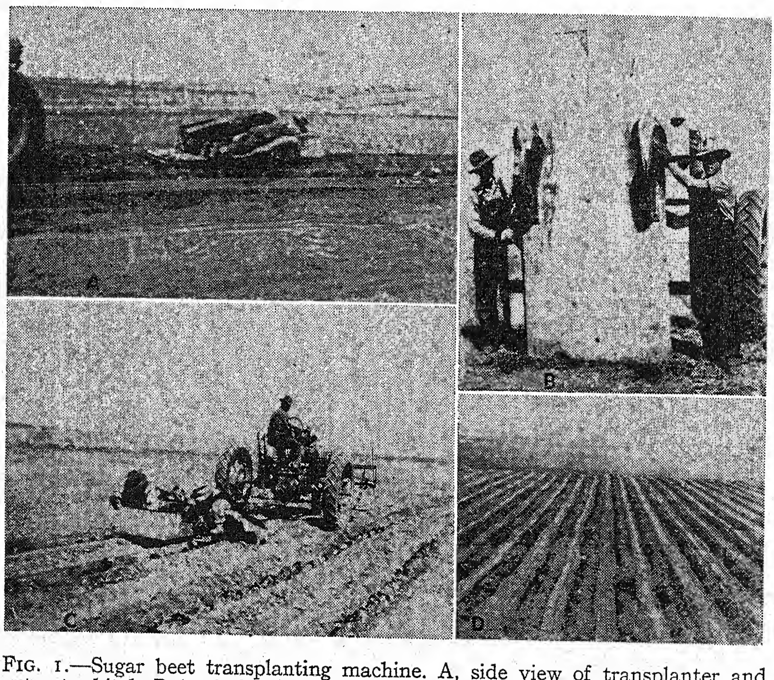


FIG. 1.—Sugar beet transplanting machine. A, side view of transplanter and tractor hitch; B, base of machine with furrow openers; C, machine in operation; D, completed planting.

loose soil back into the bottom of the furrows. The operators set the beets in these furrows by hand. Small beets are set upright and, if too short for the depth, are placed on the sides of the furrow. Larger beets are placed in the loose soil in the bottom of the furrow and extra large or extra long beets are placed on an angle, as shown in Fig. 1C. The tractor is run in low gear, the speed depending upon the spacing desired.

The rate of transplanting varies with the spacing, row length, operators, beets, etc. With beets averaging 3 inches in diameter, spaced 18 inches apart in rows 300 feet long, three men, with some experience, were able to transplant 2,500 beets per hour.

After transplanting, the beets are covered by using beet cultivator discs. Two rows are covered at a time, with a disc traveling on each side of a row throwing the soil over the plants. Better results are obtained by going over the field twice rather than by trying to cover the plants completely in one operation. Fig. 1D shows a completed seed beet planting after the beets have been covered by the discs. Irrigation furrows may be made where it is desirable to irrigate immediately.

The resulting stand of beets in the field where the machine was used was equal to the stands obtained by hand planting and the man hours required was only a fraction of those necessary for hand planting.—FRANK F. LYNES, *Beet Seed Breeding Department, Holly Sugar Corporation, Sheridan, Wyo.*

ANNUAL LESPEDEZAS ARE USEFUL IN CONSERVATION-TYPE ROTATIONS FOR THE SOUTHERN PIEDMONT

THE annual Korean and Kobe lespedezas are rapidly finding a place in crop rotations in the Southeast. Preliminary results obtained from runoff plots located on Cecil soils at the Southern Piedmont Conservation Experiment Station, Watkinsville, Ga., indicate that 2- and 3-year rotations consisting of small grain, Kobe lespedeza and cotton are practical for both land protection and soil improvement of the moderately eroded crop land of average 7% slope in the Southern Piedmont.

During the rotation cotton years, lespedeza residue after effects were responsible for lowering the water losses, reducing soil losses by two-thirds to three-fourths, and substantially increasing the cotton yield. The check method was continuous cotton, fertilized the same as the rotation cotton.

A review of 4 years' records (1940–43), obtained from comparable runoff plots representing normal terrace-interval slope length of 70 feet on a 7% slope, indicate for continuous cotton an average annual loss of 22% of the rainfall as runoff, 29 tons per acre soil loss, and a yield of 0.45 bale per acre.

During the same period, two successive cycles of a 2-year rotation consisting of oats for grain-Kobe lespedeza for seed, then cotton, allowed as a rotation annual average but 15.5% runoff and only 7.4 tons per acre of soil loss. The rotation cotton yielded 0.63 bale per acre, or 54% increase over continuous cotton grown the same years.

During the same 4-year period two 3-year rotations begun in 1940 and 1941, respectively, and consisting of oats for grain-first year Kobe lespedeza for seed, volunteer 2nd year Kobe lespedeza for hay, then cotton, produced still more beneficial results. The 3-year rotations averaged an annual loss of but 12.5% of the rainfall as runoff, 5.4 tons per acre of soil, and the rotation cotton yielded 0.81 bale per acre, or 74% increase over continuous cotton grown the same years.

In explaining the significance of these preliminary results to visiting groups of farmers and others on Station tours, the staff find it most effective to present soil losses in terms of the prospective "life of the present topsoil", associated with the several cropping methods. In these terms, it appears that land in continuous cotton production on terrace intervals of 7% slope will lose its present topsoil to the 6-inch depth in some 35 years' time; the 2-year rotation in 136 years' time; and the 3-year rotation in 189 years' time—on the basis of an extension of 4 years' soil loss data. A prospective "topsoil life" of 200 years is assumed to indicate a satisfactory degree of erosion control for rotation crop lands.

Both rotations reduced the cotton acreage but sharply increased the per acre yields. This improved the efficiency of cotton production at the same time that it provided needed crop land acreage for growing grain, hay, and seed crops. Similar rotations, based on lespedeza, have increased the yields of wheat, oats, corn, and grain sorghum in extensive Station field tests.

Lespedeza is a particularly adaptable and useful crop in that it is highly protective as a close-growing cover during the summer erosive season, and also as stubble during winter. Its residues are definitely valuable for improvement of depleted crop lands. It may ~~be~~ handled as farm needs require, without too much concern about losing its good after-effects, provided that a good amount of residue remains on the land after harvest to be at least partially turned under. Residue sods should be broken in the fall or winter, or at least a month in advance of summer row crop planting to induce decomposition and settle the seedbeds.—B. H. HENDRICKSON, *Project Supervisor, Southern Piedmont Conservation Experiment Station, Watkinsville, Georgia.*

JOURNAL

OF THE

American Society of Agronomy

VOL. 36 NOVEMBER, 1944 NO. 11

EFFECT OF NITROGEN AND PHOSPHORUS ON THE YIELD AND ROOT ROT RESPONSES OF EARLY AND LATE VARIETIES OF COTTON[1]

LESTER M. BLANK[2]

LOSSES occasioned by the attack of the root rot fungus, *Phymatotrichum omnivorum* (Shear) Duggar, are severe in certain of the cotton-producing sections of Texas and other areas of the Southwest. The literature pertaining to the field and laboratory investigations on various phases of the root rot disease has been reviewed in recent years by Streets (11)[3] and by Rea (7). The possibility of minimizing the losses from root rot in cotton through the use of nitrogen and phosphorus fertilizers in conjunction with early- and late-maturing varieties of cotton has been investigated in the present study.

LITERATURE

Commercial fertilizers were used by Reynolds and Rea (8) on root rot infested soils in Bell County, Tex. Increased yields resulted, particularly from fertilizers containing phosphoric acid, but the margin of increase was not considered profitable. More extensive investigations of the use of fertilizers with cotton in the blacklands of Texas are reported by workers of the former Soil Fertility Station of the U. S. Dept. of Agriculture, located at Austin, Tex. (1, 2, 4, 5, 6). Their work indicates that the dominant need of the soils of the Houston series is for nitrogen, while that of the Wilson series is for phosphate. The tendency for nitrogen fertilizers to decrease root rot and for phosphate fertilizers to increase root rot is most pronounced on the Wilson series, while on the Houston series the trend is the same but to a lesser degree. The results of chemical analyses of various portions of the cotton plants (2) indicated that the differences in mortality of cotton secured in fertilizer experiments on certain Wilson soils are associated with outstanding differences in the total nitrogen and the total P_2O_5 content of the root bark.

It has been pointed out by Rogers (10) that a high early or mid-season kill of cotton by root rot results in a markedly decreased yield, and that fair yields may

[1]Contribution from the Bureau of Plant Industry, Soils and Agricultural Engineering, Agricultural Research Administration, U. S. Dept. of Agriculture, in cooperation with the Texas Agricultural Experiment Station, College Station, Tex. Approved by the Texas Agricultural Experiment Station as Technical Contribution 858. Received for publication August 23, 1944.

[2]Pathologist. The writer wishes to express his appreciation to Dr. H. D. Barker and Mr. Curtis L. Mason, Division of Cotton and Other Fiber Crops and Diseases, for assistance in planning the experiment and in recording and analyzing the results.

[3]Numbers in parenthesis refer to "Literature Cited", p. 887.

be obtained in continuous cotton even under root rot conditions "provided the soil is in fertile condition, and, by chance, root rot is delayed until late season". The importance of the stage of boll formation in relation to the time of onset of disease symptoms and death of the plant is emphasized by Streets (11). He states that an early maturing variety of cotton "avoids the usual heavy losses in yield, as the crop is largely matured before the period of greatest mortality to the cotton plant arrives".

Cotton varieties showing a range of maturity were studied in date-of-planting tests on infested soil by Taubenhaus and Killough (12) and by Dana and Rea (3). The latter reported no difference in disease attributable to varieties, while the former reported slightly greater susceptibility in the early-maturing variety. Both found that, in general, with the later plantings the percentage of disease was decreased.

METHODS AND MATERIALS

The experiments, factorial in design, were conducted in 1940, 1941, and 1942 on Houston black clay near Brenham, Washington County, and on Crockett clay loam near Caldwell, Burleson County, Tex. Both fields were in cotton in 1939, and intermittently in preceding years. Root rot was prevalent in both fields in 1939, although the degree of infestation was somewhat less on the Crockett clay loam at Caldwell than on the Houston black clay at Brenham. In these experiments the old cotton stalks were bedded during the winter and the fertilizers were applied by hand in the open furrow and the land rebedded some 10 days or more before planting of cotton in mid-April.

The treatments included 12–0–0, 12–8–0, and 0–8–0 fertilizers, applied at the rate of 600 pounds per acre. The fourth treatment, or check, was without fertilizer. The fertilizer contained nitrogen in equal parts from sodium nitrate and ammonium sulfate, and phosphoric acid from superphosphate.[4] Treatments were repeated for 3 years on the same plots at Brenham, but at Caldwell the experiment was on a different area each year.

The eight varieties of cotton used in the experiment were selected as being representative of early- and late-maturing types, based upon their performance in 1938 and 1939 in date-of-picking and yield tests in the Brazos Valley (9). The early-maturing varieties included Stoneville 2B, Delfos 531B, Bennett Quick, and Oklahoma Triumph No. 5. The later-maturing varieties were New Boykin, Lankart, Sunshine, and Mebane (A. D. estate).

The 32 variety-fertilizer plots were randomized in six replicates, the following main effects and interactions being partially confounded with sub-blocks: N (nitrogen), P (phosphorus), $N \times P$, $N \times V_7$ (nitrogen $\times$ early var. vs. late var.), $P \times V_7$, and $N \times P \times V_7$. Single-row plots 50 feet long were used each year at each location. Within the limits of the partial confounding the fertilizers were randomized in each true block and the varieties were then randomized in relation to the fertilizers. Thus, in each block each of the four fertilizer treatments appeared eight times, each of the eight varieties appeared four times, and a given fertilizer-variety combination appeared but once. The location of varieties in relation to fertilizers was re-randomized each year of the experiment.

The planting dates varied from April 10 to April 18. The following data were secured: Stand records, periodic disease records, and early and late yield records. The disease records are based upon the number of plants in each plot showing above-ground symptoms of root rot, and those records made in late July or early August, shortly before the first picking was made, are considered to be most indicative of the effect of fertilizers and varieties upon the incidence of root rot and the yield of cotton.

EXPERIMENTAL RESULTS

DISEASE DATA

The seasonal development of root rot at each location during each of the 3 years of the experiment is illustrated graphically in Fig. 1.

[4]The fertilizers were prepared through the courtesy of J. E. Adams, formerly Soil Technologist, Soil Fertility Station, Austin, Tex.

In all 3 years the disease was more severe at Brenham than at Caldwell. Rainfall records maintained at the Brenham plot showed that the precipitation for the period May 1 to August 1 for these years was well above the long-time average as compiled for the city of Brenham weather station, some 10 miles distant. There is no evidence that moisture was a limiting factor in disease development at either location during any of the 3 years of the experiment.

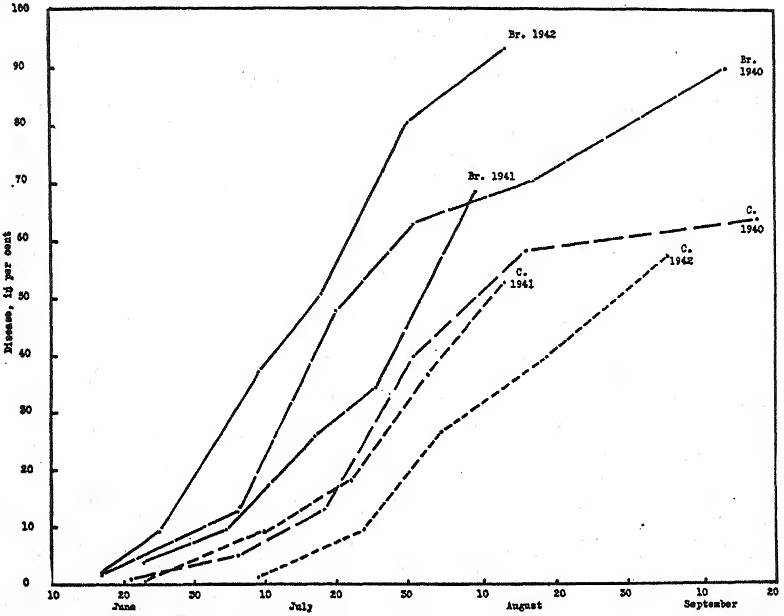


FIG. 1.—Graph showing development of disease throughout the season at Brenham (Br.) and Caldwell (C.) in 1940, 1941, and 1942.

The pre-harvest disease data are presented in Tables 1 and 2, for Brenham and Caldwell, respectively, and show the mean value for each of the 32 variety-fertilizer combinations at each location each year. Analyses of variance were made of the disease and yield data for each year at each location, but only the combined analyses of variance of the disease and yield data for all years at each location are presented in Table 3. Although the data were analyzed on the basis of 31 comparisons or sources of variance, it has seemed advisable to lump many of the individual sources of variance in the summary of the analyses in Table 3, particularly since many of the comparisons were not significant statistically or were interactive effects of little interest.

In Table 3 high significance is indicated for the effect of N at Brenham. The disease data in Table 1 show that with nitrogen present (12–0–0 and 12–8–0 fertilizers) less disease was recorded than with nitrogen absent (0–8–0 and 0–0–0 fertilizers) in 1940 and 1942, while in 1941 the reverse condition prevailed. However, for the 3 years as a whole the mean effect of nitrogen present was to

TABLE 1.—*The effect of fertilizers and varieties upon the percentage of root rot in cotton grown on Houston black clay, Brenham, Tex., in 1940, 1941, and 1942.*

Year	Fertilizer				Mean, all fertilizers
	0-0-0	0-8-0	12-0-0	12-8-0	
Stoneville 2 B					
1940	70.7*	77.5	33.3	57.2	59.7
1941	63.2	70.2	65.5	72.3	67.7
1942	83.5	87.8	66.8	69.0	76.8
Mean	72.5	78.5	55.2	66.2	68.1
Delfos 531 B					
1940	81.7	85.7	61.5	71.7	75.1
1941	86.8	79.5	72.3	79.7	79.6
1942	86.8	79.3	85.0	91.2	85.6
Mean	85.1	81.5	72.9	80.9	80.1
Bennett Quick					
1940	77.8	61.5	32.7	61.0	58.3
1941	60.2	73.3	62.0	73.8	67.3
1942	83.8	79.7	74.3	83.5	80.3
Mean	73.9	71.5	56.3	72.8	68.6
Oklahoma Triumph No. 5					
1940	88.2	75.5	43.3	62.7	65.9
1941	67.2	68.3	73.8	73.2	70.6
1942	91.3	90.2	71.3	84.2	84.8
Mean	80.2	78.0	62.8	73.4	73.6
Mean, All Early Varieties					
1940	78.1	75.1	42.7	63.1	64.7
1941	69.3	72.8	68.4	74.7	71.3
1942	86.3	84.3	74.3	82.0	81.7
Mean	77.9	77.4	61.8	73.3	72.6
New Boykin					
1940	69.7	59.0	59.5	56.2	61.1
1941	75.3	72.0	71.7	66.2	71.3
1942	90.8	78.8	67.7	75.3	78.1
Mean	78.6	69.9	66.3	65.9	70.2
Lankart					
1940	79.3	70.5	56.8	67.3	68.5
1941	65.2	51.5	73.0	73.2	65.7
1942	83.2	83.8	70.2	82.7	80.0
Mean	75.9	68.6	66.7	74.4	71.4

TABLE 1.—*Concluded.*

Year	Fertilizer				Mean, all fertilizers
	0-0-0	0-8-0	12-0-0	12-8-0	
Sunshine					
1940	65.3	68.7	34.5	65.5	58.5
1941	58.3	61.8	64.2	71.8	64.0
1942	84.8	83.7	68.3	69.7	76.6
Mean	69.5	71.4	55.7	69.0	66.4
Mebane (A. D. estate)					
1940	67.0	77.8	68.5	54.7	67.0
1941	68.5	60.2	72.0	60.5	65.3
1942	76.2	93.5	74.5	71.7	79.0
Mean	70.6	77.2	71.7	62.3	70.4
Mean, All Late Varieties					
1940	70.3	69.0	54.8	60.9	63.8
1941	66.8	61.4	70.2	67.9	66.6
1942	83.7	84.9	70.2	74.8	78.4
Mean	73.6	71.8	65.1	67.9	69.6
Mean, All Varieties					
1940	74.2	72.1	48.7	62.0	64.3
1941	68.1	67.1	69.3	71.3	68.9
1942	85.0	84.6	72.3	78.4	80.1
Mean	75.8	74.6	63.4	70.6	71.1

*Average of six replicates.

lower the amount of disease to a highly significant extent. A similar trend was apparent in the disease records at Caldwell Table 2) with nitrogen present reducing the amount of disease by a highly significant margin in 1941, by a significant margin in 1940, while in 1942 the reduction in disease was not significant statistically. For the 3-year period at Caldwell the reduction in disease due to the presence of nitrogen was highly significant. Inasmuch as nitrogen was one of the partially confounded sources of variance, and but five of the six replicates of a given treatment were used in the analysis, the effect of N present or N absent is based upon 80 measurements or replicates of each in a given year and location, or 240 measurements of each for the 3-year analyses.

In the comparison of phosphorus present (0-8-0 and 12-8-0) vs. phosphorus absent (0-0-0 and 12-0-0) no statistically significant difference could be observed on the Houston soil of the Brenham plot. However, at the Caldwell plot the mean effect of phosphorus present was to increase the amount of disease by a significant margin in 1940, to a highly significant extent in 1941, and to a highly significant

TABLE 2.—*The effect of fertilizers and varieties upon the percentage of root rot in cotton grown on Crockett clay loam, Caldwell, Tex., in 1940, 1941, and 1942.*

Year	Fertilizer				Mean, all fertilizers
	0-0-0	0-8-0	12-0-0	12-8-0	
Stoneville 2 B					
1940	49.3*	37.2	26.0	39.0	37.9
1941	32.2	40.5	27.5	29.7	32.5
1942	21.0	21.5	14.7	27.2	21.1
Mean	34.2	33.1	22.7	32.0	30.5
Delfos 531 B					
1940	39.7	49.5	23.8	39.2	38.1
1941	56.5	48.0	24.5	42.2	42.8
1942	54.2	27.5	24.2	48.7	38.7
Mean	50.1	41.7	24.2	43.4	39.9
Bennett Quick					
1940	44.3	44.8	36.5	42.2	41.9
1941	36.5	33.3	27.0	28.7	31.7
1942	23.8	24.2	8.5	25.8	20.6
Mean	34.9	34.1	24.0	32.2	31.3
Oklahoma Triumph No. 5					
1940	34.3	47.5	39.7	27.3	37.2
1941	43.2	66.0	37.0	30.7	44.2
1942	42.3	32.8	9.7	27.2	28.0
Mean	39.9	48.8	28.8	28.4	36.5
Mean, All Early Varieties					
1940	41.9	44.7	31.5	36.9	38.8
1941	42.1	46.9	29.0	32.8	37.7
1942	35.3	26.5	14.3	32.2	27.1
Mean	39.8	39.4	24.9	34.0	34.5
New Boykin					
1940	34.7	56.5	41.0	41.3	43.4
1941	42.3	46.8	30.5	39.0	39.7
1942	26.7	23.3	36.2	15.3	25.4
Mean	34.6	42.2	35.9	31.9	36.1
Lankart					
1940	48.8	51.2	43.7	29.0	43.2
1941	24.0	39.7	29.5	34.3	31.9
1942	34.2	30.8	44.5	16.7	31.5
Mean	35.7	40.6	39.2	26.7	35.5

TABLE 2.—*Concluded.*

Year	Fertilizer				Mean, all fertilizers
	0–0–0	0–8–0	12–0–0	12–8–0	
Sunshine					
1940	37.0	31.5	37.0	33.0	34.6
1941	33.2	58.8	24.8	27.7	36.1
1942	20.7	16.3	29.0	26.7	23.2
Mean	30.3	35.5	30.3	29.1	31.3
Mebane (A. D. estate)					
1940	37.0	49.7	25.5	47.7	40.0
1941	37.8	43.2	31.7	22.0	33.7
1942	24.7	20.7	37.2	16.2	24.7
Mean	33.1	37.9	31.4	28.6	32.7
Mean, All Late Varieties					
1940	39.4	47.2	36.8	37.7	40.3
1941	34.3	47.1	29.1	30.7	35.3
1942	26.6	22.8	36.7	18.7	26.2
Mean	33.4	39.0	34.2	29.0	33.9
Mean, All Varieties					
1940	40.7	45.9	34.1	37.3	39.5
1941	38.2	47.0	29.1	31.7	36.5
1942	30.9	24.7	25.5	25.5	26.7
Mean	36.6	39.2	29.6	31.5	34.2

*Average of six replicates.

margin for the 3 years as a whole. The interaction of N × P did not reach significance at any time.

Of the seven comparisons involving varietal effects alone only two are of particular interest in regard to the disease reaction. V 1 comparison, Stoneville 2B vs. Delfos 531B, was highly significant at Caldwell in 1942, at Brenham in 1940 and 1941, and significant at at Brenham in 1942 as a result of the greater amount of disease in the Delfos variety. The comparison of the four early varieties vs. the four late varieties (V 7) was significant at Brenham in 1941, while in 1940 and 1942 the trend towards a higher disease count in the early varieties did not reach significance. In Table 3 significance at odds of 19:1 for this comparison is indicated. In 2 of the 3 years at Caldwell the early varieties as a group had a slightly higher disease value than the late-maturing varieties, but in the combined analysis significance is not attained. The remaining varietal comparisons, Bennett Quick vs. Oklahoma Triumph (V 2), New Boykin vs. Lankart (V 4), Sunshine vs. Mebane (V 5), the first two early varieties vs. the second two early varieties (V 3), and the first two late varieties vs. the last two late varieties (V 6) are thrown together as V 2–6 in

the analyses in Table 3 inasmuch as the differences were, on the whole, not significant.

TABLE 3.—*Analyses of variance for the effect of nitrogen, phosphorus, and varieties of cotton upon the incidence of disease and yield of seed cotton at two locations for 3 years.*

Source of variance	Brenham			Caldwell		
	D/F	Mean square		D/F	Mean square	
		Root rot affected plants	Yield of seed cotton		Root rot affected plants	Yield of seed cotton
Block Comparisons:						
Years	2	12,685*	34.84*	2	8,741**	184.52**
Blocks	5	24,102**	60.41**	15†	8,069**	3.90**
Error (a) (B×Y)	10	1,877	5.84			
Sub-blocks	6	6,857**	14.91**	18‡	1,381**	3.28**
Error (b) (Sb×Y)	12	738	2.43			
Treatments:						
Nitrogen	1	2,493**	38.65**	1	5,161**	23.25**
Phosphorus	1	121	1.83	1	4,404**	5.65**
N×P	1	227	0.50	1	30	0.69
Variety 1§	1	5,196**	16.91**	1	3,145**	4.53**
V1×N	1	629	8.73**	1	309	0.09
V1×P	1	364	0.00	1	15	0.83
Variety 7¶	1	1,305*	27.96**	1	49	54.33**
V7×N	1	51	4.76**	1	10	0.00
V7×P	1	77	0.06	1	621	1.59*
Variety 2–6††	5	513	4.97**	5	441	4.23**
V2-6×N	5	120	0.89	5	182	0.23
V2-6×P	5	301	0.52	5	85	0.12
N×P×V1-7	7	495	0.85	7	545	1.06**
Error (c)	149	279	0.75	—	—	—
Year interactions:						
Y×N	2	4,415**	4.57**	2	168	1.94**
Y×P	2	125	0.04	2	1,402*	2.85**
Y×V1	2	134	1.22	2	914	0.03
Y×V7	2	175	4.05**	2	184	4.49**
Y×V2-6	10	221	0.74	10	451	1.68**
Y×N×P						
Y×N×V1-7						
Y×P×V1-7	44	210	0.71	44	268	0.83**
Y×N×P×V1-7						
Error (d)	298	225	0.64	447	419	0.33
Total	575	631	1.82	575	684	1.44

*Significant (odds 19:1).
**High significance (odds 99:1), using the four errors indicated for Brenham and the completely pooled error (447 D/F) for Caldwell.
†Blocks within years.
‡Sub-blocks within years.
§Comparison of the variety Stoneville 2B vs. Delfos 531B.
¶Comparison of the four early varieties vs. the four late varieties.
††Varietal comparisons other than V1 and V7 specified above.

YIELD DATA

The mean effect of the presence of nitrogen (12–0–0 and 12–8–0) was to increase the yields of seed cotton to a highly significant margin

over that obtained in the absence of nitrogen (0–8–0 and 0–0–0). This difference occurred all 3 years at both locations (Tables 4 and 5).

TABLE 4.—*The effect of fertilizers and varieties upon the yield in pounds of seed cotton on root rot infested Houston black clay, Brenham, Tex., in 1940, 1941, and 1942.*

Year	Fertilizer				Mean, all fertilizers
	0–0–0	0–8–0	12–0–0	12–8–0	
Stoneville 2 B					
1940	2.08*	1.90	4.15	3.73	2.97
1941	1.37	1.17	1.83	1.69	1.51
1942	1.67	1.37	2.78	3.35	2.29
Mean	1.71	1.48	2.92	2.92	2.26
Delfos 531 B					
1940	1.47	1.32	2.67	2.20	1.91
1941	0.81	0.66	1.49	1.12	1.02
1942	1.62	2.53	1.73	1.27	1.79
Mean	1.30	1.50	1.96	1.53	1.57
Bennett Quick					
1940	1.72	2.37	3.38	2.83	2.57
1941	1.42	1.12	1.89	1.48	1.48
1942	1.53	1.78	2.37	2.18	1.97
Mean	1.56	1.76	2.55	2.16	2.01
Oklahoma Triumph No. 5					
1940	1.60	1.70	3.43	2.60	2.33
1941	1.41	1.53	1.95	2.08	1.74
1942	1.58	0.88	2.97	2.75	2.05
Mean	1.53	1.37	2.78	2.48	2.04
Mean, All Early Varieties					
1940	1.72	1.82	3.41	2.84	2.45
1941	1.25	1.12	1.79	1.59	1.44
1942	1.57	1.64	2.46	2.39	2.02
Mean	1.52	1.53	2.55	2.27	1.97
New Boykin					
1940	1.62	2.07	1.65	2.32	1.91
1941	0.77	0.99	1.11	1.31	1.05
1942	0.80	1.62	2.85	2.47	1.93
Mean	1.06	1.56	1.87	2.03	1.63
Lankart					
1940	1.18	1.63	1.90	1.40	1.53
1941	0.66	1.06	1.12	1.17	1.00
1942	1.52	1.40	2.07	1.57	1.64
Mean	1.12	1.36	1.70	1.38	1.39

TABLE 4.—*Concluded.*

Year	Fertilizer				Mean, all fertilizers
	0-0-0	0-8-0	12-0-0	12-8-0	
		Sunshine			
1940	1.85	1.63	3.00	2.22	2.17
1941	1.36	1.27	1.45	1.38	1.37
1942	1.57	1.80	2.87	2.92	2.29
Mean	1.59	1.57	2.44	2.17	1.94
		Mebane (A. D. estate)			
1940	0.88	1.18	0.93	1.58	1.14
1941	0.65	0.86	1.01	1.45	0.99
1942	1.27	0.50	1.68	2.03	1.37
Mean	0.93	0.85	1.21	1.69	1.17
		Mean, All Late Varieties			
1940	1.38	1.63	1.87	1.88	1.69
1941	0.86	1.05	1.17	1.33	1.10
1942	1.29	1.33	2.37	2.25	1.81
Mean	1.18	1.34	1.80	1.82	1.53
		Mean, All Varieties			
1940	1.55	1.73	2.64	2.36	2.07
1941	1.05	1.09	1.48	1.46	1.27
1942	1.43	1.49	2.41	2.32	1.91
Mean	1.34	1.44	2.18	2.05	1.75

*Average of six replicates.

The reduction in the amount of disease in the presence of nitrogen in 2 of the 3 years at Brenham and in all 3 years at Caldwell is probably responsible in large part for the increased yields. However, it should be noted that the yield at Brenham in 1941 was increased with the addition of nitrogen despite the fact that a highly significant increase in disease accompanied the use of the nitrogen fertilizer.

The presence or absence of phosphorus did not affect yields significantly at Brenham (0-8-0 and 12-8-0 vs. 0-0-0 and 12-0-0). In the Caldwell experiment the mean effect of phosphorus present over the 3-year period was to increase yields by a highly significant margin, even though the amount of disease had been increased significantly by the phosphate fertilizer during 2 of the 3 years. The interaction of nitrogen and phosphorus did not attain significance at either location in the 3-year analyses, although in 1941 at Caldwell unusually heavy yields with the 12-8-0 combination contributed to the highly significant interaction of N $\times$ P.

Among the varietal comparisons Stoneville outyielded Delfos by a highly significant margin at both locations. Certain of the other varietal comparisons, indicated as V 2 to V 6 in Table 3, may be

examined in Tables 4 and 5. Bennett Quick and Oklahoma Triumph were similar in their yielding ability, while the general trend was for

TABLE 5.—*The effect of fertilizers and varieties upon the yield in pounds of seed cotton on root rot infested Crockett clay loam, Caldwell, Tex., in 1940, 1941, and 1942.*

Year	Fertilizer				Mean, all fertilizers
	0-0-0	0-8-0	12-0-0	12-8-0	
Stoneville 2 B					
1940	0.88*	2.05	1.53	1.31	1.44
1941	1.67	0.98	1.77	2.40	1.71
1942	3.47	2.65	4.52	3.10	3.43
Mean	2.01	1.89	2.61	2.27	2.19
Delfos 531 B					
1940	0.87	1.10	1.45	1.05	1.12
1941	0.74	1.13	1.48	1.80	1.29
1942	2.08	3.35	4.17	2.85	3.11
Mean	1.23	1.86	2.37	1.90	1.84
Bennett Quick					
1940	0.95	1.33	1.25	1.35	1.22
1941	1.13	0.98	1.02	1.82	1.24
1942	2.52	2.45	3.47	2.97	2.85
Mean	1.53	1.59	1.91	2.05	1.77
Oklahoma Triumph No. 5					
1940	1.20	1.63	1.12	0.38	1.08
1941	0.90	0.81	1.13	2.23	1.27
1942	2.97	3.12	4.03	3.67	3.45
Mean	1.69	1.86	2.09	2.09	1.93
Mean, All Early Varieties					
1940	0.97	1.53	1.34	1.02	1.21
1941	1.11	0.97	1.35	2.06	1.37
1942	2.76	2.89	4.05	3.15	3.21
Mean	1.61	1.80	2.25	2.08	1.93
New Boykin					
1940	0.87	0.78	0.62	1.92	1.05
1941	0.55	0.61	0.70	1.01	0.72
1942	2.32	2.55	2.52	2.95	2.59
Mean	1.25	1.31	1.28	1.96	1.45
Lankart					
1940	0.37	0.58	0.57	1.72	0.81
1941	0.55	0.63	0.83	1.22	0.81
1942	2.38	1.88	2.48	2.78	2.38
Mean	1.10	1.03	1.29	1.91	1.33

TABLE 5.—*Concluded.*

Year	Fertilizer				Mean, all fertilizers
	0-0-0	0-8-0	12-0-0	12-8-0	
			Sunshine		
1940	0.62	1.07	0.82	1.60	1.03
1941	0.68	0.81	0.82	1.20	0.88
1942	2.57	2.83	2.95	3.05	2.85
Mean	1.29	1.57	1.53	1.95	1.59
			Mebane (A. D. estate)		
1940	0.42	0.33	0.23	2.27	0.81
1941	0.39	0.49	0.52	0.65	0.51
1942	1.42	1.08	1.35	1.80	1.41
Mean	0.74	0.63	0.70	1.57	0.91
			Mean, All Late Varieties		
1940	0.57	0.69	0.56	1.88	0.93
1941	0.54	0.63	0.72	1.02	0.73
1942	2.17	2.09	2.33	2.65	2.31
Mean	1.09	1.13	1.20	1.85	1.32
			Mean, All Varieties		
1940	0.77	1.11	0.95	1.45	1.07
1941	0.83	0.80	1.03	1.54	1.05
1942	2.47	2.49	3.19	2.90	2.76
Mean	1.35	1.47	1.73	1.97	1.63

*Average of six replicates.

New Boykin to outyield Lankart and for Sunshine to outyield Mebane. The comparison of all early varieties against all late varieties (V 7) gave yield values consistently in favor of the early maturing group. Only at Brenham in 1942 did the margin of difference fail to attain high significance (odds 99:1).

DISCUSSION

From the nature of the factorial experiment the main effects of the factors under consideration here were determined on the basis of a large number of replicates each year at each location. It follows, therefore, that the trends attributed to the main factors or sources of variance may be interpreted with greater confidence than results obtained in simpler experiments and with fewer replications.

The results are in general accord with the findings of other workers with fertilizers on soils of the Houston and Wilson series. The reduction in the amount of root rot through the application of relatively high rates of nitrogen fertilizer was outstanding in 2 of the 3 years on each of the two soil types studied in these experiments. The mean effect of phosphorus was to increase the amount of disease and the

yield of seed cotton on the Crockett clay loam of the Caldwell plot while on the Houston black clay at Brenham phosphorus was ineffective as regards the amount of disease or yield of cotton.

Under conditions of medium to severe root rot infestation, these data suggest that on Houston black clay the highest yields of cotton may be obtained with the 12–0–0 fertilizer, while on the lighter soil of the Crockett series the highest mean yield values occurred with the 12–8–0 fertilizer. In considering the response of early- and late-maturing groups of varieties to nitrogen and phosphorus, it is evident that at both locations the early varieties, as a group, yielded slightly better with 12–0–0 than with 12–8–0. On the Houston soil the late-maturing group yielded essentially the same with 12–0–0 as with 12–8–0, while at Caldwell the mean values were definitely higher with the 12–8–0 fertilizer.

For the 3 years the four early varieties showed a slightly higher percentage of root rot than did the four later-maturing varieties, apparently as a result of the unusual susceptibility of Delfos variety. If the contribution of this variety was eliminated from the disease data, the mean disease response for the remaining three early varieties and for the four late varieties would be essentially the same at both locations.

Outstanding differences in yields have been observed between the two groups of varieties despite their rather uniform disease reaction. During all 3 years at Caldwell and in 2 of the 3 years at Brenham, the early-maturing varieties outyielded the late varieties by a highly significant margin. Although the yielding ability of these varieties on noninfested soil may vary to approximately this same extent, it is obvious that from a practical standpoint the use of good-yielding, early-maturing varieties of cotton should be encouraged where it is necessary to plant cotton on root rot infested fields.

SUMMARY

A study of the effect of nitrogen and phosphorus fertilizers in combination with early and late maturing varieties of cotton upon the incidence of root rot and the yield of seed cotton was made on two soil types in Texas over a period of 3 years. The mean effect of nitrogen was to decrease the amount of disease by a significant or highly significant margin in 2 of the 3 years at each location, and yields were increased by a highly significant margin in all years at both locations. Phosphorus had no appreciable effect upon disease or yield at one location, while at the second location both disease and yield were increased in 2 of the 3 years. Although early varieties as a group were as susceptible to disease as the later varieties, they outyielded the latter group by a highly significant margin in all years at one location and in 2 of the 3 years at the second location.

LITERATURE CITED

1. ADAMS, J. E., JORDAN, H. V., and JENKINS, P. M. The response to fertilizers of soils of the blackland prairie section of Texas as determined by the triangle system. Jour. Amer. Soc. Agron., 32:677–663. 1940.

2. ————, WILSON, R. C., HESSLER, L. E., and ERGLE, D. R. Chemistry and growth of cotton in relation to soil fertility and root rot. Soil Sci. Soc. Amer. Proc., 4:329–332. 1939.
3. DANA, B. F., and REA, H. E. Development of root rot in cotton planted at different dates. Phytopath., 21:120. 1931.
4. JORDAN, H. V., DAWSON, P. R., SKINNER, J. J., and HUNTER, J. H. The relation of fertilizers to the control of cotton root rot in Texas. U.S.D.A. Tech. Bul. 426. 1934.
5. ————, HUNTER, J. H., and ADAMS, J. E. The relation of fertilizers to the cotton plant produced in the blackland prairie section of Texas. Jour. Amer. Soc. Agron., 30:254–262. 1938.
6. ————, NELSON, H. A., and ADAMS, J. E. Relation of fertilizers, crop residues, and tillage to yields of cotton and incidence of root rot. Soil Sci. Soc. Amer. Proc., 4:325–328. 1939.
7. REA, H. E. The control of cotton root rot in the blackland region of Texas. Tex. Agr. Exp. Sta. Bul. 573. 1939.
8. REYNOLDS, E. B., and REA, H. E. Effect of fertilizers on the yield of cotton and on the control of root-rot disease of cotton on the blackland prairie soils of Texas. Jour. Amer. Soc. Agron., 26:313–318. 1934.
9. RICHMOND, T. R. Report of varieties of cotton tested in the Brazos river valley, 1938–1940. Tex. Agr. Exp. Sta. Progress Rpt. 722. 1941.
10. ROGERS, C. H. The effect of three- and four-year rotations on cotton root-rot in the central Texas blacklands. Jour. Amer. Soc. Agron., 29:668–680. 1937.
11. STREETS, R. B. Phymatotrichum (cotton or Texas) root rot in Arizona. Ariz. Agr. Exp. Sta. Tech. Bul. 71. 1937.
12. TAUBENHAUS, J. J., and KILLOUGH, D. T. Texas root rot of cotton and methods of its control. Tex. Agr. Exp. Sta. Bul. 307. 1923.

FOLIAR DIAGNOSIS AND PLANT NUTRITION IN FERTILIZER PLACEMENT EXPERIMENTS[1]

WALTER THOMAS, WARREN B. MACK, AND ELISHA M. RAHN[2]

IT IS a truism that the discovery of fundamental principles affecting the relations of method of application of fertilizers to weather and soil conditions cannot be made from information based solely on final yields. Up to the present time basic knowledge on the effect of various methods of fertilizer placement have been sought by means of the analysis of the soil; and although this method of approach supplies more information than that given by yields alone, soil investigations are inadequate to establish the manner of utilization of the fertilizer elements resulting from the different treatments.

In the ultimate analysis the difference in the action of different methods of fertilizer placement is reflected in the differences in the mode of nutrition of the plants. Consequently, a knowledge of the manner in which different methods of fertilizer placement modify nutrition with respect to the fertilizer elements should provide the basis for a more adequate understanding of the fundamental conditions affecting modes of fertilizer application.

The simplest way of comparing the nutrition of plants in a field experiment is by means of the periodic analysis, throughout the growth cycle, of morphologically homologous leaves taken from a convenient and suitable position (4).[3] It has been established that the composition of leaves of the same physiological (metabolic) age of a particular species grown on a relatively uniform soil under the same climatic conditions and receiving different fertilizer treatments reflects these differences in the sense that whenever a fertilizer element, whether N, P, or K, is effective, as determined by the response of the plant to that element, that response always is associated with an increase of the element in the dried foliage, as compared with the content of one that has not received that element (4). Furthermore, the composition of morphologically homologous leaves under these conditions is related to the growth and development of the differentially fertilized plants (5).

The functioning assimilating leaves, therefore, can be used as an index tissue. In this investigation the yields produced by three methods of fertilizer application are examined in relation to the nutrition of the plants as revealed by the foliar diagnosis indices. Partiticular attention is given to methods of interpretation.

Anticipating objections, it is emphasized that no replications are made in this experiment. The position taken in this respect by the

---

[1]Contribution from the Department of Horticulture, The Pennsylvania State College, State College, Pa. Authorized for publication as paper No. 1194 in the Journal Series of the Pennsylvania Agricultural Experiment Station. Received for publication October 1, 1943.

[2]Professor of Plant Nutrition, Head of Department, and Assistant Professor of Vegetable Gardening, now Assistant Horticulturist, University of Delaware, respectively.

[3]Figures in parenthesis refer to "Literature Cited", p. 902.

authors is the result of the evidence given by foliar diagnosis investigations in which replications of a specific treatment have been made (5, 6, 8, 9). Our argument has been presented in detail in other publications (8, 10). Briefly, it is this: to increase the reliability of field experiments, it is much more important to increase the number of observations than to multiply the number of replications, because yields alone are inadequate to indicate the mode of action of fertilizers, information on which is requisite for interpreting their effects on development and yield. From this point of view, data on the manner in which the course of nutrition during the growing season is related on the one hand to the fertilizer treatment applied and on the other hand to development and yield on the individual plot alone have validity.

Replications, from this point of view, supply information only on the way in which soil variations influence the nutrition of the plants, either in connection with or apart from the effects of the fertilizer treatment. In the same manner, repetitions of the same experiment in different seasons supply information only on the manner in which variations in climate influence the nutrition of the plants, provided, of course, that the necessary analyses are made to determine the course of nutrition.

If yields alone are relied upon to supply information on the action of fertilizers, no amount of replication or repetition will indicate the effects of such variations, because the manner in which differences in yield have been brought about by variations in soil and climate remains undetermined.

It is admitted that, to be valid, data on the relations of the course of nutrition to fertilizer treatment and to development and yield must be obtained from plots on which the plants are reasonably uniform and are clearly differentiated from each other in their development, among different treatments. These conditions, let it be emphasized, were fully met in the experiments described herein.

EXPERIMENTAL PROCEDURE

THE PLOTS

The experiment was conducted on a relatively uniform site on the Pennsylvania State College farm, upon which various vegetable crops had been grown for at least 10 years; for example, carrots in 1939, early beets and fall cauliflower in 1940, and cucumbers in 1941.

For at least 4 years previous to the inception of this experiment, fertilizer applications had been uniform over the entire area, medium in amount for vegetable crops, such as 600 to 800 pounds of 4-12-4 or 4-16-4 commercial fertilizer to the acre. In addition, every 2 or 3 years, a fairly heavy application of manure, about 10 tons to the acre, had been made.

The soil is a silty clay loam of the Hagerstown series, which, when limed, responds only to nitrogen, phosphorus, and potassium. This series contains all the micro nutritive elements.[4]

[4]Dr. F. G. Merkle and Dr. E. C. Dunkle of the Department of Agronomy, Pennsylvania State College, have stated (in unpublished data) that a favorable response to boron applications has been obtained from alfalfa on Hagerstown soil in certain localities in Pennsylvania. Such favorable responses, however, usually are associated with evident unfavorable physical or other conditions of the soil.

The site measuring 72 by 140 feet was divided into four plots having six rows to a plot. Seed of the Allegheny variety of sweet corn was drilled at the rate of 12 pounds to the acre on June 26 and plants were thinned to about one plant per foot of row. Rows were 3 feet apart.

A 4–16–4 fertilizer of commercial grade was used at the rate of 400 pounds to the acre, except that in the treatment in which the fertilizer was applied in solution the equivalent of 4–16–4 was used in the form of the relatively soluble fertilizers "ammo-phos" (11–48–0), muriate of potash (48%), and nitrate of soda (16%).

SAMPLING

The first sampling of leaves was made on July 25, 29 days after seeding. The procedure was to take the fourth leaf from the base together with about an inch of the sheath from all plants in row 1 of each plot, omitting sampling of the few plants the development of which was not typical of growth on the particular plot. At the next date of sampling on August 10, the fourth leaf from the base of most of the plants on plots 1 and 3 was in varying stages of senescence. As it is important to sample only functioning healthy leaves, the sixth leaf from the base was sampled in the same manner throughout the second row from each plot at this date (August 10). The sixth leaf remained green on all plants on the third and fourth dates of sampling, August 21 and September 1, respectively. Accordingly, the third and fourth rows, respectively, were sampled on these dates in like manner. The leaves were dried at 70° C, ground to pass an 80-mesh sieve, and dried at 100° C before analysis (4).

YIELDS

The weather conditions during the experiment were as follows: The mean daily temperature (72° F) up to the end of August was slightly above the 40-year average, and rainfall (12.5 inches) up to the last picking deviated only a little from the long time mean for the period.

The yields of marketable ears (unhusked) in pounds to the plot and their equivalent in tons to the acre are given in Table 1, and the detailed analytical results are presented in Fig. 1, which shows the percentage value of nitrogen, phosphoric acid, and potash at the different periods of sampling.

TABLE 1.—*Methods of fertilizer placement and yields.*

Plot No.	Method of placement of 4–16–4 fertilizer at the rate of 400 lbs. per acre	Yields	
		Lbs. per plot	Equivalent tons per acre
2	Plowed down in bands at the bottom of the furrow 7 inches deep, one band about 2 inches wide in each of the furrows; plowed on the day of seeding	421.1	3.64
3	In solution form (1 lb. to 2 gallons of water) in the row with the seed; then covered with soil	397.9	3.43
1	In a single continuous band along one side of the row, 3 inches from the row and 3 inches deep, applied with a hand plow and covered with the same plow	367.5	3.17
4	No fertilizer	264.5	2.28

METHODS OF INTERPRETATION

Two procedures are in use in interpreting the data on leaf composition. One school of thought looks upon the effect of each element on growth and development separately. Some workers of this particular school[1] assume the existence of

a minimum value or range for each nutrient which characterizes a deficiency (1, 2, 11, 12). The selection of minimum values as the indices of yield is made on the grounds that all other components will be present in amounts greater than their minimum values, with the assumption that only one dominant limiting factor is in operation at a given moment. The logical deduction from this premise is that yields will be related to the element (factor) present in minimum and not to any other element.

The other school of thought, which includes the present authors, carries one stage further the results in terms of percentage composition, by converting the data obtained from percentage values into such a form as to indicate the equilibrium between the fertilizer entities (N, P_2O_5, and K_2O) in the leaf of the rank considered at the moment of sampling. In this manner the changes in the ratios or "balance" between these elements also can be followed throughout the growth cycle. The logic of taking into consideration these relationships should be apparent, because the effect of each element on development is influenced by the others, as witnessed in the phenomenon of antagonism (reciprocal effects) among them. Both approaches will be used in the examination of the composition data of this experiment.

THE COURSE OF NUTRITION OF EACH ELEMENT CONSIDERED SEPARATELY

Fig. 1 shows the changes with maturity in the percentage values for N, P_2O_5, and K_2O in the dried foliage from the respective treatments. The graphs give a picture of the relationship of supply to and demand on the leaf of the rank considered. The greater the slope, the greater is the demand relative to supply of the particular element.

A feature of the graphs is the observation that at each sampling date throughout the period examined, the higher the levels of K_2O the higher is the yield, and that no such regular pattern with respect to all plots is exhibited in the graphs for N or P_2O_5.

NUTRITION WITH RESPECT TO POTASH

The relatively steep slopes of the graphs for K_2O of plants growing on plots 1 and 3, which received applications as a single band and in solution, respectively, show that the supply of potassium relative to demand is less from these treatments throughout the cycle than is the case with plants on the plot in which the fertilizer was plowed down in the furrow (plot 2). In the latter the supply relative to demand is at a high level throughout the cycle, and at times exceeds the demand on the leaves of this rank. But in the case of plants on the unfertilized plot the supply to the leaves of the rank considered is at a low level, although at one period it is greater than the demand.

The means of the respective values for K_2O from all samplings from each of the several treatments are given in column 5 of Table 2, and are in decreasing order of yields 3.59%, 3.38%, 3.21%, and 2.87%. These, therefore, represent the resultant values for K_2O during the growth cycle and show that in this experiment the fertilizer in a single band (plot 1) has supplied during the growth cycle less potash than fertilizer in solution form (plot 3) and the latter less than the fertilizer which was plowed down (plot 1). It has been established by a number of investigations that desiccation to which the surface soil is subjected, particularly under drought conditions, results in immobilization of potassium. These findings are in accord with such knowledge.

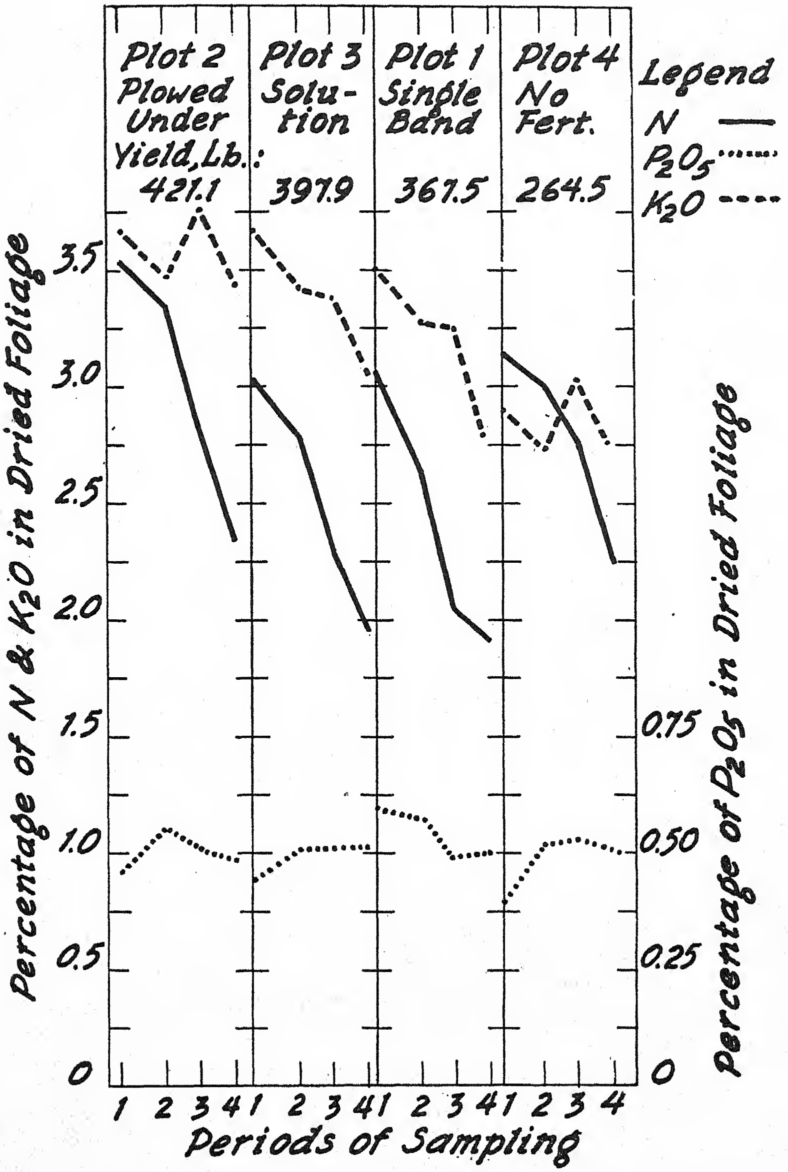


FIG. 1.—Changes during the growth cycle in the percentage composition with respect to nitrogen, phosphoric acid, and potash. Percentages as ordinates and dates of sampling as abscissas.

NUTRITION WITH RESPECT TO PHOSPHORIC ACID

The graphs are characterized by the high leaf content in this component during the early period of growth from plot 1, which

received the fertilizer as a single band, and by the low content of this element at the first date of sampling (July 25) in the leaves from plants on unfertilized plot 4, the values for plots 2 and 3 being intermediate. At the early period of growth, therefore, fertilizer placed as a solution or plowed under has not supplied so much phosphoric acid as when applied as a single band in the furrow 3 inches deep. As growth proceeds, because of variation of phosphoric acid supply in relation to demand, relationships change until at the last period (August 21 to September 1) little difference in the content of this entity is observed in plants from any of the plots. Normally, the content of phosphoric acid decreases progressively with maturity of the leaf. The slope of the graphs show a tendency to an accumulation of this constituent in the early period of growth, except in plot 1. It will be shown later in this paper that this phenomenon is the result of a disequilibrium between nitrogen and phosphoric acid.

NUTRITION WITH RESPECT TO NITROGEN

The content of this component is greatest throughout the cycle in leaves from the highest yielding plot (plot 2) in which the fertilizer was plowed under. The graphs showing the course of the nitrogen nutrition of plants on the plots in which fertilizer was applied in solution (plot 3) and in a single band (plot 1) are displaced considerably below that for the plots in which fertilizer was plowed down and even below that of the unfertilized plot even at the first date of sampling, showing the relative inefficiency of nitrogen applied in these ways in this particular experiment.

The resultant values for this component are given in Table 2, column 3. They are in order of decreasing yields, 3.01%, 2.52%, 2.41%, 2.79%, respectively. The explanation of the apparently anomalous value for the last is suggested in the values for K_2O, and will be more apparent from the data in which all three elements are considered together as a unit.

YIELDS IN RELATION TO A SINGLE ELEMENT

Since the values of potash progressively increase with increase in yield and since no regular relationship is to be observed in those for nitrogen or phosphoric acid, one school of workers, presumably, would interpret this condition as indicating that the dominant factor limiting yields of plots 1, 3, and 4 is potash, and that nitrogen and phosphoric acid are present in amounts greater than their minimum values. Some investigators belonging to this school conceive of a series of limiting factors of descending order of dominance (first, second, third, etc.). According to this interpretation, presumably, nitrogen is the second limiting factor. Further comment will be deferred until examination has been made of the relationship to yields when any two of the nutrients are considered and particularly when all three, nitrogen, phosphoric acid, and potash, are considered together.

RELATIONSHIP BETWEEN TWO NUTRIENTS

It is obvious that it is difficult to determine the relationship between the elements from the graphs of Fig. 1 in which the drifts of

each element with time are represented separately. The relationship of any two elements can be determined by plotting one as the ordinate and the other as the abscissa. As an example, the relationship between N and P_2O_5 is shown in Fig. 2. The coordinates of the samplings for the sixth leaf are shown.

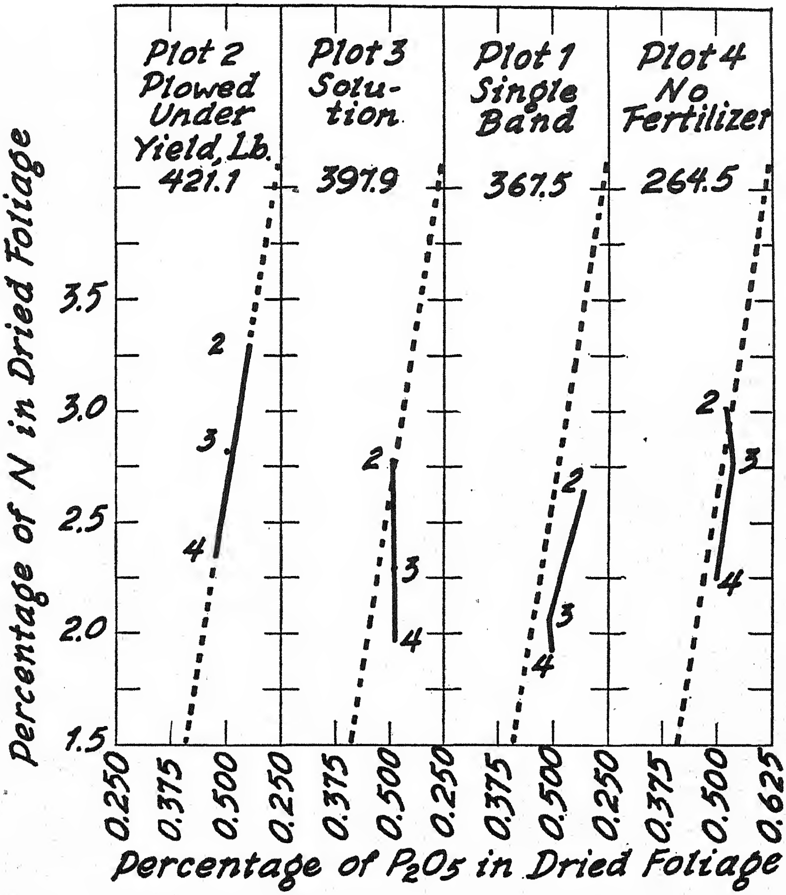


FIG. 2.—Relationship between nitrogen and phosphoric acid (sixth leaf). Percentages of nitrogen as ordinates and percentages of phosphoric acid as abscissas. Scale for phosphoric acid is doubled. Numerals on graphs refer to period of sampling.

It has been established that when growth is optimum the relationship between nitrogen and phosphoric acid with increasing maturity of the leaf is a linear one, departure from which is accompanied by reduced yields (3). As shown in Fig. 2, the relationship between N and P_2O_5 in the case of the plants from the treatment in which the fertilizer was plowed down in the furrow (plot 2) is a linear one. The

equation of the line joining the loci of the coordinates of the second and fourth samplings is $y = 6.51x-3.91$. This line is shown broken in each of the graphs of the figure. The deviation from the optimum (broken) line with respect to position, form, and length between sampling dates shows in each case the nature of the disequilibrium between N and P_2O_5 in the plants on the particular plot.

The relationship between any two of the fertilizer elements and development have traditionally been sought in the ratios thereof (N/P_2O_5, N/K_2O, and P_2O_5/K_2O) expressed as percentage values in the plant. In this way, it was frequently noted that optimum yields were associated with an N/K_2O ratio equal or nearly equal to unity, particularly in the early period of growth. But, whereas a physiological basis exists for the linear relationship between nitrogen and phosphorus under optimum growth conditions (3), there appears to exist no physiological basis for the existence of a linear relationship under optimum growth conditions between nitrogen and potassium or between phosphorus and potassium, which may result from the fact that potassium does not form a part of the structural tissues.

POTASH NOT SOLE FACTOR LIMITING YIELDS

The relationships indicated in Fig. 2 and described above lead to the conclusion that potash is not the sole factor giving rise to the differences in yields from the plots in this experiment. In fact, the positions of the graphs of plots 1 and 3 relative to those of plot 2 show that in the former nitrogen is much too low, both absolutely and relatively to phosphoric acid.

RELATIONSHIP BETWEEN ALL THREE NUTRIENTS

QUANTITY AND QUALITY FACTORS OF NUTRITION

The fundamental concepts involved in the relationship of *all three* components to development as represented by yields have been described elsewhere (4). Interpretation is based on consideration of the values representing the *quantity* factor of nutrition and the *quality* factor also. The former, conveniently designated the intensity of nutrition, is obtained from the sum of the percentage values ($N + P_2O_5 + K_2O$) in the dried foliage at the moment of sampling; and the quality factor, which represents the relations between them and, consequently, the equilibrium, balance, or ratios between these components (N, P_2O_5, and K_2O), also at the moment of sampling, is expressed by a value designated the NPK unit. This unit is derived by converting the percentage values for each element (or entity) into milligram equivalents and then finding the proportion each bears to the milligram equivalent total. The results are multiplied by 100 to avoid fractional quantities.

The values for the quantity and quality factors of nutrition derived in the manner described are designated the "foliar diagnosis indices". In the interpretation of results it is important to remember that any response to the addition of a fertilizer will be accompanied by a change in (a) the intensity of nutrition or in (b) the balance between the elements as indicated by the composition of the *NPK unit* or in

(a) and (b) simultaneously. It follows that values representing the intensity factors might be identical or nearly so in plants from plots showing widely different yields under different conditions of nutrient supply, whereas the quality factor as represented by the values of the *NPK unit* of the plants considered may be widely different, and conversely.

INTENSITY INDICES

The values for the intensity of nutrition (Fig. 3, right) for each sampling can be plotted in a manner analogous to the graphs of Fig. 1 in which the course of nutrition of each element is considered separately. The relative positions of the graphs representing the intensities of nutrition show the relative supply of all three nutrients during the cycle. Plot 2, in which the fertilizer was plowed down, supplies the greatest quantities. Although the supply relative to demand is high at the first period (July 25 to August 10) to plants of plots 1 and 3, the relative positions of the graphs of these plots in relation to that of plot 4 during the last period shows supply relative to demand to be inadequate.

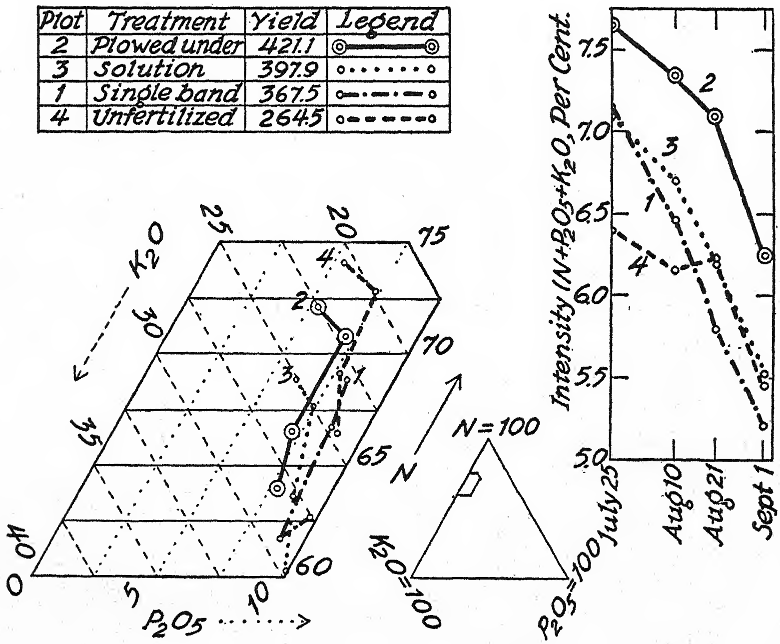


FIG. 3.—Drifts in the equilibrium or balance between nitrogen, phosphoric acid, and potash during the growth cycle. Numerals indicate the treatment number and are placed at the locus of the coordinate at the first sampling. Top right hand corner, changes in the intensity values with leaf maturity. The small triangle indicates the portion of the whole triangle, of which each side equals 100, shown in the diagram at the left.

EQUILIBRIUM INDICES

The relationship between three variables, however, can be shown only by means of trilinear coordinates, as in Figs. 3 and 4, which must not be confused with the triangular fertilizer system of Schreiner and others. In these figures, to conserve space, only the part of the triangle in which the values lie is shown. The small triangle at the lower right-hand side of the figure indicates the portion of the entire triangle, of which each side equals 100, and of which the summit apex equals 100% of N, the right base apex 100% of P_2O_5, and the left base apex 100% of K_2O in the composition of the *NPK unit*, which is represented in the larger diagram at the left-hand side of the figure. The construction and use of such a triangle has been described (7).

As the locus representing the $N - P_2O_5 - K_2O$ equilibrium moves upward from the base toward the summit apex, the amount of N that is the quota-part of nitrogen in the composition of the unit increases. Similarly, as the locus of a point moves away from the right-hand side towards the left base apex, the quota-part of K_2O in the unit increases, and displacements from the left-hand side towards the right base apex indicate increasing proportions of P_2O_5. The numerals in the figure correspond to the numbers of the plots and are placed at the loci of the first sampling, July 25. The loci at successive samplings can be followed by tracing the path followed by a line.

CHANGES IN THE QUALITY FACTOR OF NUTRITION WITH MATURITY

The drifts of the equilibrium values (Fig. 3, left) with maturity are of a similar type in plants on all plots, indicating that the influence of environmental (meteorological) factors on the changes in the equilibrium with respect to the components considered is alike or nearly so in all treatments. Thus, in all cases during the first period, July 25 to August 10, there is a drift in the equilibrium towards the right base apex (P_2O_5 = 100) and away from the summit (N = 100) indicating an increase in the relative proportion of K_2O and P_2O_5 made at the expense of the N; but the displacement during this period is less in treatment 1 (single band) than in the others. Thereafter the paths followed results in larger increases in the proportion of K_2O in all cases, and in plants from plots 3 and 4 (solution and unfertilized, respectively) of P_2O_5 also made at the expense of N.

The practical significance of the direction of the drifts is that in not one of the fertilized plots has the addition of nitrogen tended to oppose or counteract the influence of the meteorological conditions in this particular year in causing nitrogen to play a minor role relative to phosphoric acid and potash, indicated by the progressive decline in the quota-part of N in the unfertilized plot.

RESULTANT FOLIAR DIAGNOSIS INDICES

The simplest means of determining the relationship of yields to nutrition, as represented by foliar diagnosis data, is to express these data in terms of a resultant value representing the integration of all changes in the intensities and *NPK unit* values during the cycle.

Thus the resultant value representing the changes during the cycle in the composition of the *NPK unit* in any particular treatment will be represented by one point only, which will be the center of gravity of the diagram for the particular treatment considered. Obviously, the foliar diagnosis values represented by the coordinates of this point will be identical with the mean values. Similarly the resultant value of the changes in the intensity of nutrition during the cycle in any particular case will be represented by the mean value.

The resultant values are shown numerically in Table 2 and diagrammatically in Fig. 4.

Plot	Treatment	Intensity	Yield
2	Plowed under	7.10	421.1
3	Solution	6.39	397.9
1	Single band	6.16	367.5
4	Unfertilized	6.15	264.5

Legend

Plot	
2	◉ Optimum
1	• Treatment 1
3	• " 3
4	• " 4

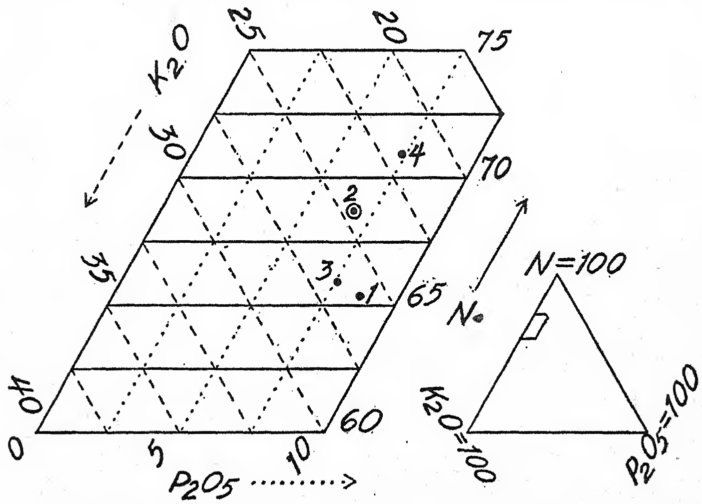


FIG. 4.—Relative positions of the loci of the resultant *NPK unit* values, indicating the equilibrium between N–P_2O_5–K_2O during the growth cycle. Numerals refer to the treatments. Top left hand corner, resultant values for intensity of nutrition. The small triangle indicates the portion of the whole triangle, of which each side equals 100, shown in the diagram at the left.

It is important to note that the relationships among the *NPK unit* values representing the balance between the components are not always similar to those between the percentages of the individual components. For example, the percentage of N is greater in the leaves from plot 2 than in those from plot 4, whereas the proportion of N in the *NPK unit* is greater in the leaves from plot 4 than in those of plot 2. Again, the percentage of K_2O also is highest in the leaves from the optimum plot 2, but the proportion of K_2O in the *NPK unit* is next to the lowest. Similarly, the lowest proportion of P_2O_5 in the

NPK unit is in the leaves from plot 2, but the percentage of P_2O_5 is next to the highest.

Table 2, column 6 shows that the intensity of nutrition increases progressively as yields increase. Although the difference between the intensity of nutrition of plants growing on the plot in which fertilizer was applied as a single band (plot 1) and that of the unfertilized plot (plot 4) is quite small, however, as we shall see later, great differences occur in the quality of nutrition as indicated by the composition of their *NPK units*. This case presents an example of yield differences produced solely by differences in the relationships among the fertilizer elements, the quantitative factor being identical in each.

TABLE 2.—*Resultant values during the growth cycle of the data for percentage composition, intensity of nutrition, and equilibrium values as represented by the composition of the NPK unit in relation to yields.*

Plot No.	Treatment	N, %	P_2O_5, %	K_2O, %	Intensity $N+P_2O_5+K_2O$, %	Composition of NPK unit, $N:P_2O_5:K_2O$	Yield, lbs.
2	4-16-4 fertilizer placed 7 in. deep in furrow and plowed down	3.01	0.498	3.59	7.10	68.79:6.74:24.47	421.1
3	4-16-4 fertilizer applied as solution in the row	2.52	0.492	3.38	6.39	65.90:7.63:26.47	397.9
1	4-16-4 fertilizer applied 3 in. deep in single band	2.41	0.540	3.21	6.16	65.35:8.67:25.98	367.5
4	Unfertilized	2.79	0.487	2.87	6.15	70.90:7.33:21.77	264.5

With respect to the *NPK units*, it is to be noted (Table 2, column 7), that now no regular gradient of the K_2O values is found in relation to yields as occurs among the data for the percentage values for this component (Table 2, column 5). The distinction is of importance, because, as already emphasized, the *NPK unit* values indicate the relationship of nitrogen, phosphoric acid, and potash to one another, in other words the balance among all of them.

The maximum yield (treatment 2) corresponds to a value of 7.10 for the intensity of nutrition and of 68.79 : 6.74 : 24.47 for the *NPK unit*. The type of development represented by the plants on this plot corresponds, for the rank of leaves selected, to these foliar diagnosis values and supplies a base or standard of reference to which the nutrition of the other plots in this experiment can be referred. This optimum is not to be regarded as a fixed constant, because the mode of nutrition is dependent not only on the fertilizer applied, but on other factors, such as rainfall and temperature which vary from year to year. For these particular plots in this particular year these foliar

diagnosis indices provide concrete information on the nutritional factors producing the differences in yields.

FOLIAR DIAGNOSIS INDICES RELATIVE TO THE OPTIMUM

In this experiment the nutrition of plants on the lower yielding plots has the following relationships to that of the highest yielding plot, which will be referred to as the "optimum".

Plot 4 (*unfertilized*).—The value of the intensity (6.15) is much too low, the proportion of N and P_2O_5 in the composition of *NPK unit* is too high, and that of K_2O too low, thus defining the nature of the disequilibrium.

Plot 1 (*Fertilizer applied as single band*).—The value for the intensity (6.16) is but slightly higher than in the morphologically homologous leaves of the plants on unfertilized plot 4, but the loci of the *NPK units* of the plants on these plots are widely divergent. This is an example indicating that the fertilizer has acted to change the balance of nutrients without affecting their quantitative relationships, resulting in widely different yields. In the plants of plot 1, the quota-part of N is too low relative to the optimum, whereas P_2O_5 and K_2O are too high. This defines the nature of the disequilibrium.

Plot 3 (*Fertilizer applied as solution*).—The value for the intensity (6.39) is still well below that of the "optimum", but is higher than in the leaves of plants for the preceding plots. The character of the disequilibrium between N, P_2O_5, and K_2O is similar to that of the plants which received fertilizer in a single band, namely, the proportion of nitrogen relative to that of the "optimum" is too low and that of phosphoric acid and potash too high.

The addition of fertilizer in solution form has operated to increase the yield over that from fertilizer applied in a single band, through an increase in the intensity of nutrition and a shift in the NPK equilibrium nearer to that of the optimum compared with that applied as a single band 3 inches deep.

It is clear, therefore, that with adequate intensity of nutrition the nearer the locus of a point approaches to that of the "optimum", the higher will be the yield. This has been found to be true in all our experiments.

SUMMARY

The method of foliar diagnosis has been applied to the examination of the nutrition, with respect to the fertilizer elements, of sweet corn grown under three different methods of placement of a 4:16:4 fertilizer applied at the rate of 400 pounds to the acre.

The highest yield of unhusked ears was obtained by plowing down the fertilizer in a band at the bottom of the furrow at a depth of 7 inches, followed in order of yields by the plot receiving the fertilizer in solution form in the row, and then by the plot to which the fertilizer was applied in a single band beside the row at a depth of 3 inches.

The relationships of the data of leaf composition to the yields obtained under the different methods of placement are adequately expressed by means of "the foliar diagnosis indices", which are defined.

The points of departure from the methods of traditional agronomy are discussed.

LITERATURE CITED

1. BATJER, L. P., and MAGNESS, J. R. Potassium content of leaves from commercial orchards. Proc. Amer. Soc. Hort. Sci., 36:197–201. 1938.
2. HOAGLAND, D. R., and ARNON, D. I. Physiological aspects of availability of nutrients for plant growth. Soil Sci., 51: 431–444. 1941.
3. THOMAS, WALTER. Mathematical expression of equilibrium between nitrogen and phosphoric acid in plants. Science, 84:422–423. 1936.
4. ———. Foliar diagnosis: Principles and practice. Plant Phys., 12:571–600. 1937.
5. ———, and MACK, WARREN B. Foliar diagnosis in relation to development and fertilizer treatment of the potato. Jour. Agr. Res., 57:397–414. 1938.
6. ———, ———. Foliar diagnosis. The influence of the soil on the action of fertilizers. Plant Phys., 14:75–92. 1939.
7. ———, ———. Salient features of the method of foliar diagnosis. Proc. Amer. Soc. Hort. Sci., 37:253–260. 1939.
8. ———, ———. Foliar diagnosis in relation to soil heterogeneity. Soil Sci., 52:455–468. 1942.
9. ———, ———. Foliar diagnosis study of climatic influences on the nutrition of spring and fall grown greenhouse tomatoes. Plant Phys. 16: 117–144. 1941.
10. ———, ———. Misconceptions relative to the method of foliar diagnosis. Proc. Amer. Soc. Hort. Sci., 44:355–361. 1944.
11. ULRICH, ALBERT. Potassium content of grape leaf petioles and blades contrasted with soil analysis as an indication of the potassium status of the plant. Proc. Amer. Soc. Hort. Sci., 41:206–212. 1942.
12. ———. Nitrate content of grape leaf petioles as an indicator of the nitrogen status of the plant. Proc. Amer. Soc. Hort. Sci., 41:213–218. 1942.

STUDIES IN THE MINOR ELEMENT NUTRITION OF VEGETABLE CROP PLANTS: I. THE INTERRELATION OF NITROGEN, PHOSPHORUS, POTASH, AND BORON IN THE GROWTH OF RUTABAGAS[1]

R. H. White-Stevens and P. H. Wessels[2]

THE problem of minor element nutrition of crop plants has received increasing attention from physiologists, soil chemists, fertilizer specialists, and practical growers. This may be readily substantiated by reference to the frequency with which the subject recurs in current agronomic literature. The plant nutrient which has received most attention among the so-called "minor elements" is boron.

In general, studies dealing with the boron nutrition of plants have constituted, on the one hand, the identification of the deficiency upon various crops, on various soil types, and under various conditions, and, on the other hand, the determination of the "tolerance" limits of boron nutrition for crops grown under field conditions.

Although these considerations are important and a necessary step in the practical solution of the problems of the commercial grower, frequently the results are found to belie satisfactory replication even under conditions presumably constant. A great deal of confusion has therefore arisen, and unfortunately, not a little real misgiving on the part of practical men. Thus, for example, carefully replicated tests over a period of several years have indicated with statistical significance, that 10 pounds of commercial borax applied per acre will adequately protect cauliflower against "brown rot" under Long Island conditions (5).[3] Yet, in spite of careful practice of this recommendation, reports are made at the conclusion of the season that "brown rot" did occur in such treated fields, with quality and market demand of the crop consequently reduced. Such apparent exceptions cannot be ascribed in all cases to inefficiency, poor dissemination of the borax, or to mistaken identity in the diagnosis. They represent, in some cases, true failure of the recommendation to fulfill its requirement. Other factors are involved, how many and to what extent can only be ascertained by experiment, but related nutritional factors are distinct possibilities. It is the purpose of these studies to explore this field.

Although few studies have approached this problem by the factorial method, Purvis and Hanna (10) have drawn attention to the possible interrelative effects of potash and boron, and Powers and Bouquet (9) have noted that in studies of "black canker" of table beet, additional potash fertilizer in the absence of borax aggravated the condition.

---

[1]Paper No. 220 Department of Vegetable Crops, Cornell University, Ithaca, N. Y. Also read before the Division of Fertilizer Chemistry, American Chemical Society, Detroit, Mich., September 11, 1940. Received for publication January 27, 1944.

[2]Assistant Research Professor and Research Professor in Vegetable Crops, Long Island Vegetable Research Farm, Riverhead, N. Y., respectively.

[3]Figures in parenthesis refer to "Literature Cited", p. 921.

Chandler (2), in an extensive study of boron nutrition in the genus *Brassica*, showed that boron deficiency symptoms were accentuated by a high calcium level in the substrate, but could not find any interaction between boron and nitrogen, boron and potash, boron and calcium, and/or boron and magnesium, where boron was held at the single deficiency level of 0.5 p.p.m. and the other four elements alone were varied factorially at three levels each. It was noted, however, that some variation in deficiency appeared, suggesting that some combination of the associated elements might possibly affect the variation, even though no main effect due to a single element was apparent. Recently, Reeve and Shive (11), conducting greenhouse culture experiments on tomato and corn, have indicated a possible negative interaction between boron and potassium. The incidence of the deficiency symptoms apparently became more pronounced as the potassium level in the substrate was increased without a concomitant increase in the boron level.

PRELIMINARY FIELD STUDIES

This study arose as a result of failure to explain the cause of certain obvious anomalies occurring on a series of permanent fertility plots at the Long Island Vegetable Research Farm at Riverhead, N. Y. These plots were laid out in 1923 and have received their respective treatments consistently during the intervening years. Thus, those plots which were designed to develop certain nitrogen, phosphorus, or potash nutrition levels have had ample time to attain these levels, be they high, medium, or low. In recent years certain of these high-fertility plots have failed to yield crops anticipated from the fertilizer applied. The cause of this is being investigated and to date the most significant feature that has developed is the variable intensities of minor element deficiencies arising in direct association with the long time major element experimental program. Chief of these minor element problems now appears to be boron deficiency.

Table 1 gives the yields, percentage of roots showing boron-deficiency symptoms, the average weight of the normal and "diseased" roots, and the related statistical parameters of a crop of beets grown on this particular series of fertility plots during 1940.

These data clearly indicate that on table beets, a crop found to be sensitive to boron deficiency under Long Island conditions (13) and elsewhere (9), the mere repeated application of the three major fertilizers, nitrogen, phosphorus, and potash, had induced significant differences in the degree of boron deficiency.

The deficiency induced by these three fertilizer elements, however, cannot be ascribed to the same cause. In the case of the nitrogen series, a significant positive linear effect and a significant negative quadratic effect in the yield data show the optimum yield was secured from the 40-pound N per acre application, higher applications significantly reducing the yield. Concomitant with this, the percentage of boron deficiency significantly declined—linear effect—the major part of the decline arising from the lower nitrogen applications—

quadratic effect. Analysis of the data for the average size of normal and diseased roots, however, showed the diseased roots to be consistently larger than the normal roots and that the ratio in size between the two types of roots did not change significantly over the nitrogen series.

TABLE I.—*Yields and boron-deficiency counts of beets grown over ranges of nitrogen, phosphorus, and potash fertilizers.*

Fertilizers applied annually, lbs. per acre			Roots per acre, tons	Plants showing symptoms, %	Average weight per root, grams	
N	P_2O_5	K_2O			Normal	Diseased
0	0	0	2.11	0.0	46	—
0	240	120	4.06	24.3	80	173
40	240	120	14.07	20.6	98	169
80	240	120	11.85	16.7	91	166
120	0	120	3.39	3.4	52	142
120	80	120	9.17	9.5	90	126
120	160	120	16.27	13.1	85	140
120	240	0	12.88	6.4	78	240
120	240	40	14.29	11.5	97	188
120	240	80	13.96	11.9	101	133
120	240	120	12.49	15.6	96	116
Standard error			2.05	0.4	37.42	
Least diff. at 5% point			3.49	0.4		

Resolution of treatment effects to single degrees of freedom

Factor	Variance and mean effect signs			
Linear nitrogen	26.61+*	197.13−***	1320−	3456+
Quadratic nitrogen	21.95−*	5.76−***	1290−	433+
Cubic nitrogen	11.39+	2.04+***	5−	512+
Linear phosphorus	44.94+**	601.70+***	297+	2803+
Quadratic phosphorus	19.76−*	1.10−*	93−	26−
Cubic phosphorus	0.31	16.02−***	7−	1203+
Linear potash	0.11−	388.08+***	10212−*	17787−***
Quadratic potash	2.07−	23.52−***	45+	1335+
Cubic potash	0.18+	33.02+***	166+	22222−***
Least variance at 5% point	18.27	0.66	5712	
Least variance at 1% point	34.02	1.24	10234	
Least variance at 0.1% point	62.24	2.31	17654	

*Significant at 5% point.
**Significant at 1% point.
***Significant at 0.1% point.

Obviously, therefore, one has to conclude under the conditions of this experiment that applied nitrogen tends to reduce boron deficiency symptoms even though it increases yield at the lower applications, but also that at all applications boron deficiency develops in the roots after they have attained a certain "threshold" size which

remains essentially constant for all levels of nitrogen applied. This suggests that nitrogen alone can help to control boron deficiency on sensitive crops. Incidently, the source of nitrogen employed in this experiment was synthetic sodium nitrate and ammonium nitrate, so essentially no borated materials were applied.

The phosphate series show there was a significant increase in yield with the optimum at 160 pounds of P_2O_5 per acre, a significant rise in percentage boron deficiency essentially paralleling the yield curve up to its optimum, and a significant size difference between diseased and nondiseased roots, but, as in the nitrogen series, there was no significant change in the ratio between these two root classes over the phosphate series.

Phosphorus evidently increased the incidence of the deficiency, but as the yield increased also in like degree and as the ratio of root size between diseased and nondiseased plants is essentially constant, the increase in the percentage of diseased roots can be readily ascribed to increasing numbers of the roots passing the "threshold" size value above which boron-deficiency symptoms are likely to occur, under these conditions.

The potash series provides a third and entirely different type of data. First, the yield is not affected over the whole series, the percentage of disease climbs rapidly with increasing acceleration—significant linear and cubic effects—and the ratio between the diseased and nondiseased root sizes progressively declines over the series, this decline being solely due to a reduction in the average size of the diseased roots, the nondiseased remaining essentially constant. With potash, therefore, it appears that boron deficiency increased without any increase in yield or plant size over the series, and, furthermore, the deficiency became more acute at an earlier stage in the growth of the plants, i. e., symptoms occurred in progressively smaller plants up the potash series. These facts are all highly statistically significant, in many cases surpassing odds of 999:1, and cannot, therefore, be dispatched as an odd but random occurrence. From these data it can be concluded that whether boron deficiency will occur or not on any given crop will depend partially, at least, upon the particular levels of nitrogen, phosphorus, and potash that happen to be present. There may be and probably are other factors which will also control the efficacy of boron nutrition, but it is evident that the nitrogen phosphorus, and potassium fertilizers must also be considered.

The fact that these three elements individually affect the incidence of boron deficiency immediately suggests that they might interact with one another and give other varied effects. The experiment from which these data were taken is not laid out to test this possibility as it is not designed factorially; therefore, a factorial experiment was designed to test this particular thesis.

MATERIAL AND METHODS

An experiment was set up in the greenhouse which involved nitrogen, phosphorus, potash, and boron applications in the nutrient solution each at "high' and "low" levels in all possible combinations, as given in Table 2.

This was a 2^4 factorial experiment with four replications.

TABLE 2.—*Molal concentration of the various nutrients employed to give the different levels of the four element factors in the factorial experiment on rutabagas.*

Treatment No.	Factor level*				Molal concentration of nutrients†						
	N	P	K	B	$Ca(NO_3)_2$	KH_2PO_4	$Na_2B_4O_7$	$CaCl_2$	KCl	HCl	NaH_2PO_4
1	−	−	−	−	0.00052	0.0018	0.00000924	0.00468	———	———	———
2	+	−	−	−	0.0052	0.0018	0.00000924	———	———	0.00936	———
3	−	+	−	−	0.00052	0.0018	0.00000924	0.00468	———	———	0.0162
4	−	−	+	−	0.00052	0.0018	0.00000924	0.00468	0.0162	———	———
5	−	−	−	+	0.00052	0.0018	0.000924	0.00468	———	———	———
6	+	+	−	−	0.0052	0.0018	0.00000924	———	———	0.00936	0.0162
7	+	−	+	−	0.0052	0.0018	0.00000924	———	0.0162	0.00936	———
8	+	−	−	+	0.0052	0.0018	0.000924	———	———	0.00936	———
9	−	+	+	−	0.00052	0.018	0.00000924	0.00468	———	———	———
10	−	+	−	+	0.00052	0.0018	0.000924	0.00468	———	———	0.0162
11	−	−	+	+	0.00052	0.0018	0.000924	0.00468	0.0162	———	———
12	+	+	+	−	0.0052	0.018	0.00000924	———	———	0.00936	———
13	+	+	−	+	0.0052	0.0018	0.000924	———	———	0.00936	0.0162
14	+	−	+	+	0.0052	0.0018	0.000924	———	0.0162	0.00936	———
15	−	+	+	+	0.00052	0.018	0.000924	0.00468	———	———	———
16	+	+	+	+	0.0052	0.018	0.000924	———	———	0.00936	———

*+ = high; − = low.

†All treatments also contained 0.015M $MgSO_4$; 1 p.p.m. $FeCl_2$, Zn $(C_2H_3O_2)_2$; and 0.1 p.p.m. $HgBr_2$, $CoCl_2$, $NiCl_2$, NaF, K_2Cr_2O, KI, $CuSO_4$, and $Al_2(SO_4)_3$.

Rutabaga was employed as the test plant, as it has been repeatedly shown to be susceptible to boron deficiency and grows well during the winter. The "Long Island Improved" variety was used.

The culture medium was acid-washed bank sand, obtained locally. The vessels employed were 4-gallon glazed crocks, with a drainage tap.

The culture solution was based upon Shive's best solution. The "high" levels of nitrogen, phosphorus, and potash were those concentrations called for in Shive's best solution, while the "low" levels were one tenth of these concentrations. "High boron" was 10 p.p.m. of boron and "low boron" was 0.1 p.p.m. of boron. The actual nutrient concentrations applied are given in Table 2.

The water employed was tap water from the local water works. This water was found to be adequate for this work after careful analysis to ensure that its mineral content would in no way obviate the conditions of the experiment. Analytical tests were made repeatedly upon this water during the progress of the experiment.

Applications were made once a week beginning when the seed germinated and continuing until the best plants were 6 to 8 inches tall, at which time the applications were increased to two per week. Water was supplied as needed. All cultures were thoroughly leached the day before the nutrient applications were made.

The experiment was commenced on August 29 and concluded on the succeeding March 28th.

When the experiment was started, 30 seeds were sown in each crock, 10 at three equally spaced points. After germination these were reduced to two at each of the three points, and when the best plants attained 6 to 8 inches in height, they were thinned again to three plants per pot. These thinnings were carefully washed free of sand, weighed fresh, and dried to constant weight.

At the final harvest, which was carried out as soon as the worst series approached death, fresh weights of whole plants, root, and foliage were recorded. Every root was cut and graded for the degree of boron-deficiency symptom apparent.

Statistical reduction of the data was carried out by methods fully described by Yates (14, 15) and Fisher (3, 4).

EXPERIMENTAL RESULTS

YIELD DATA

The effect of the differential fertility levels became apparent early in the growth of the crop and in Table 3 are presented the plant weights and mean fertility effects as they appeared by the time the best plants were 6 to 8 inches high and the last thinning was conducted. From Table 3 it can be concluded that at the time these plants were thinned the only factor actively controlling growth was nitrogen. Although the main effects of phosphorus and of potash were insignificant, the interaction between these two factors was significant. High potash interacted with phosphorus mutually to reduce growth.

Table 4 gives the average fresh weight (grams) of the entire plants, their roots, and their foliage at the final harvest, and also gives the mean effect calculations for the single degree of freedom comparisons of the single factors and related interactions. A summary of the variance analyses of these data is given in Table 5.

These data indicate that the relative effect of each factor upon the growth of the plants as a whole followed a descending magnitude of N> B> P> K>, which shows that boron, a so-called minor element, had a relatively greater main effect upon growth than either phosphorus or potash. Nitrogen, boron, and phosphorus all showed significant positive main effects, potash, on the other hand, showed a slightly

TABLE 3.—*Yield and effects induced by fertility factors on growth of rutabaga seedlings.*

Nutrient levels†				Yield, grams per plant	Mean effects	Nutrient factors
N	P	K	B			
−	−	−	−	1.06	5.86	O
+	−	−	−	4.74	3.72***	N
−	+	−	−	1.03	−0.34	P
+	+	−	−	4.75	−0.22	N P
−	−	+	−	0.78	0.02	K
+	−	+	−	5.51	0.00	N K
−	+	+	−	1.00	−0.45*	P K
+	+	+	−	4.59	−0.37	N P K
−	−	−	+	0.99	−0.01	B
+	−	−	+	4.67	−0.22	N B
−	+	−	+	1.17	−0.16	P B
+	+	−	+	4.95	−0.06	N P B
−	−	+	+	1.46	−0.05	K B
+	−	+	+	5.58	−0.23	N K B
−	+	+	+	1.08	−0.28	P K B
+	+	+	+	3.50	−0.08	N P K B

*Significant at 5% point.
***Significant at 0.1% point.
†+ = high level; − = low level.

negative main effect, which under the conditions of the experiment did not quite attain significance.

These main effects occurred in similar trend on both the roots and foliage, as would, of course, be expected.

As in the field data presented earlier, potash had little effect apart from its influence upon the effect of the other nutrient factors.

There were several significant first-order interactions among the entire plant data, namely, N × P, N × K, N × B, and P × B. The details of these interactions are worked out in Table 6.

The nitrogen × phosphorus interaction (NP) showed that these two nutritional factors were mutually beneficial to one another, each giving the best result when the other was "high".

The nitrogen × potash interaction (NK) was of a similar nature to the NP interaction, except it was of greater magnitude and perhaps a little surprising in that potash was distinctly deleterious when nitrogen was low but beneficial when nitrogen was high.

The nitrogen × boron interaction (NB) was similar to the NK interaction, the boron effect being inverted from a negative to a positive effect by increased nitrogen.

The phosphorus × boron interaction (PB) was different from the other three first-order interactions discussed in that each factor appeared to reduce the effect of the other, giving a negative interaction. Either phosphorus or boron was more effective when the other factor was "low", suggesting two possibilities, either each could, to some extent, replace the physiological efficacy of the other, or that they were mutually antagonistic. However, as boron was more effective when phosphorus was low than was phosphorus when boron was low, i.e., 280.56 grams difference to 218.18 grams difference, and yet the

TABLE 4.—*Yields and effects induced by fertility factors on growth of rutabagas.*

Nutrient levels†				Entire plant		Root only		Foliage only		
N	P	K	B	Weight, grams	Mean effects	Weight, grams	Mean effects	Weight, grams	Mean effects	Nutrient factor
−	−	−	−	125.58	644.45	114.09	465.53	11.49	179.65	O
+	−	−	−	796.63	1,065.07***	596.65	729.66***	199.98	337.57***	N
−	+	−	−	256.31	144.00*	229.49	121.55**	26.82	19.64*	P
+	+	−	−	1,117.65	58.65*	778.65	47.70	339.00	9.95	N P
−	−	+	−	49.41	−14.62	47.79	−15.37	1.62	1.38	K
+	−	+	−	753.63	82.34*	531.32	68.98*	222.31	10.87	N K
−	+	+	−	71.50	−54.05	65.70	−24.55	5.80	−30.88*	P K
+	+	+	−	1,152.51	1.04	846.22	25.33	306.29	−25.22	N P K
−	−	−	+	51.32	211.96**	47.93	128.58**	3.39	79.99*	B
+	−	−	+	1,219.97	235.32**	841.99	155.71**	397.98	82.11*	N B
−	+	−	+	198.76	−74.49*	180.00	−36.00	18.76	−40.99*	P B
+	+	−	+	1,427.25	−74.49*	996.93	−40.68	430.32	−40.93*	N P B
−	−	+	+	50.90	−57.08	45.30	41.59	5.60	11.70	K B
+	−	+	+	1,525.30	18.92	1,012.98	10.90	512.32	5.74	N K B
−	+	+	+	84.81	−52.00	75.32	−33.41	9.49	−14.33	P K B
+	+	+	+	1,413.46	−51.17	1,038.13	−32.27	375.33	−14.25	N P K B

*Significant at 5% point.
**Significant at 1% point.
***Significant at 0.1% point.
†+ = high level; − = low level.

TABLE 5.—*Analysis of variance of data of fresh weight (grams) of rutabaga seedlings, of mature plants, roots, and foliage, and of grade indices of boron-deficiency symptoms.*

Source	Degrees freedom	Variance				
		Seedlings	Mature plants	Mature roots	Mature foliage	Boron-deficiency symptom
Total	63	—	—	—	—	—
Treatments	15	139.62	86230.86	40242.33	8881.27	91.60
Blocks	3	109.95	656.00	371.66	3.00	33.66
Remainder	45	4.90	1251.82	705.76	216.82	3.20
Standard error		2.21	35.88	26.57	14.73	1.79
Calculated treatment F value		28.48	68.88	57.02	40.96	28.63
Req. F value at 0.1% point		3.64				

TABLE 6.—*Details of the N×P, N×K, N×B, and P×B interactions with respect to mean fresh weight of entire plants.**

Nitrogen×Phosphorus				Nitrogen×Potash			
Factors	Nitrogen		Across difference	Factors	Nitrogen		
Phosphorus	High	Low		Potash	High	Low	Across difference
High	1277.72	152.84	1124.88	High	1211.22	64.15	1147.07
Low	1076.38	69.80	1006.58	Low	1140.37	157.99	982.38
Down difference	201.34	83.04	Interaction 58.65	Down difference	70.85	−93.84	Interaction 82.34

Nitrogen×Boron				Phosphorus×Boron			
Factors	Nitrogen		Across difference	Factors	Phosphorus		
Boron	High	Low		Boron	High	Low	Across difference
High	1396.49	96.45	1300.04	High	781.07	711.87	69.20
Low	955.10	125.70	829.40	Low	649.49	431.31	218.18
Down difference	441.39	−29.25	Interaction 235.32	Down difference	131.58	280.56	Interaction −74.49

*Data gram means of 16 pots.

highest yield was secured from the high level of both together, then the indication is that boron can replace deficient phosphorus more effectively than can phosphorus replace deficient boron.

TABLE 7.—*Details of the NK and NB interactions on the roots and the NB, PK, and PB interactions on the foliage of rutabagas.**

Roots

Nitrogen × Potash

Factor	Nitrogen		Across difference
Potash	High	Low	
High	857.16	58.53	798.63
Low	803.55	142.88	660.67
Down difference	53.61	–84.35	Interaction 68.98

Nitrogen × Boron

Factor	Nitrogen		Across difference
Boron	High	Low	
High	972.51	87.14	885.37
Low	688.21	114.27	573.94
Down difference	284.30	–27.13	Interaction 155.71

Foliage

Nitrogen × Boron

Factor	Nitrogen		
Boron	High	Low	Across difference
High	428.99	9.31	419.68
Low	266.89	11.43	255.46
Down difference	162.10	–2.12	Interaction 82.11

Phosphorus × Potash

Factor	Phosphorus		
Potash	High	Low	Across difference
High	176.75	185.46	–8.71
Low	203.75	153.21	50.54
Down difference	–27.00	32.25	Interaction –29.62

TABLE 7.—*Concluded.*

Phosphorus × Boron

Factor	Phosphorus		
Boron	High	Low	Across difference
High	208.47	229.82	−21.35
Low	169.48	52.88	116.60
Down difference	38.99	176.94	Interaction −68.97

*Data gram means of 16 pots.

The NB interaction occurred in the roots and foliage in a similar manner as it did in the whole plant, but the other interactions did not. A significant and corresponding NK effect appeared in the root data but not in the foliage data, an NP interaction did not appear in either the root or foliage data, a PB effect appeared also in the foliage data, and a PK effect occurred only in the foliage data. This clearly indicates that the nutritional factors exert differential effects upon the two parts of the plant, and that the relation of the nutrient factors with each other varies in different parts of the same plant.

The precise details of these variable effects are given in Table 7 for each of these significant first-order interactions as they occurred in the root and foliage data.

The NB interactions on the roots and foliage are of interest in that the effect of increasing either nitrogen or boron was greater on the foliage than on the roots. Thus, increasing nitrogen when boron was high caused a weight increase of 1,116% in the roots and 4,608% in the foliage, while increased nitrogen at the low boron level caused corresponding increases of 602% and 2,335%, respectively. Similarly, raising the boron level while nitrogen was high effected increases of 141% and 161% in the roots and foliage, respectively, while increased boron when nitrogen was low caused a reduction in root weight of 26% and in foliage weight of 19%. This obviously suggests that the effects these nutrient factors have on root development is predetermined by the preceding effect they might have had on foliage development. The same conclusion cannot, however, be reached with regard to the interrelation of nitrogen and potash as this NP interaction only occurred in the root data, and therefore nitrogen and potash acted independently of one another in the foliage.

The PK interaction in the foliage reveals that phosphorus and potash mutually antagonized one another in the growth of foliage, such that phosphorus was better when potash was low and potash was better when phosphorus was low, the optimum growth arising from the high phosphorus—low potash combination. However, as this particular interaction did not occur in the root data also, then evidently the PK effect on the foliage was of little consequence in the roots, and is probably of no practical significance.

The significant PB interaction in the foliage data reveals that the relation of phosphorus and boron was the same in the foliage as in the entire plant, namely, a mutually negative effect between the two factors such that each depressed the efficacy of the other. However, unlike in the whole plant data, the optimum foliage growth was secured from the high boron-low phosphorus combination, which suggests that in the foliage, at any rate, boron is more effective at replacing deficient phosphorus than is phosphorus in replacing deficient boron. As there is also a significant NPB interaction in both the whole plant and foliage data, these suggestions are more fully elaborated below.

There were only two significant second-order interactions, the nitrogen × phosphorus × boron (NPB) interaction on the entire plant and foliage data. The mean effects of these interactions were negative, indicating these three factors mutually interacted to inhibit or reduce the efficacy of each other with respect to growth of the plant as a whole and to the growth of foliage. As there was no significant NPB effect on the roots then obviously there would be a significant NPB "F" interaction where "F" indicates the contrast of "Foliage versus Roots" introduced as a fourth factor.

The details of these NPB interactions on the plant as a whole and upon its foliage are shown in Table 8. This table is somewhat unconventional as it attempts to reveal the nature of a second-order interaction from essentially a three-way table. This is likely to be confusing, perhaps, because such a table not only provides evidence of the second-order interaction, but also includes the main effects and all the first-order interactions of the three factors involved. It is essential, therefore, to realize that to understand the meaning of the second-order interaction, one must disentangle the other effects. This can be done by a process of progressive subtraction. However, this procedure entails entering the table in a unilateral rather than a trilateral manner at some point, and proceeding through the effects of each factor and ultimately eliminating all but the triple effect of the second-order interaction. This single figure secured is not, by itself, very informative, but when the process of its evaluation is laid out, then at least its biological significance is revealed.

Yates (15) shows how a second-order interaction may be computed from the data in a three-way table from expansion of the formula $\frac{1}{4}(N_2-N_1)\,(P_2-P_1)\,(B_2-B_1)$, in which the subscript value of 2 and 1 for N, P, and B represent the high and low levels of these factors in the data. Expansion of this expression, substitution of the data for the treatment notations, and ultimate calculation will, of course, give a single figure, which would correspond to the final NPB effects computed in Table 8.

From these data it can be seen that when nitrogen was low and phosphorus was low boron was deleterious in its effect upon the plant as a whole or its parts. As the phosphorus was raised, this deleterious boron effect declined, particularly in the roots, thus phosphorus reduced the deleterious boron effect when nitrogen was low. When nitrogen was high, however, boron improved growth, but phosphorus again reduced its effect. This is but one of several ways of looking

TABLE 8.—*Details of the second-order interaction nitrogen × phosphorus × boron on the growth of the entire plant foliage and roots of rutabagas.**

High N				Low N				
High P		Low P		High P		Low P		
High B	Low B	High B	Low B	High B	Low B	High B	Low B	
Entire Plant								
1,420.36	1,135.08	1,372.64	775.13	141.79	163.91	51.11	87.59	Yields, grams
285.28		597.51		−22.12		−36.38		B effects
−312.23				14.26				P/B effects
−297.97/4 = −74.49								N/P/B effects
Foliage								
402.83	322.65	455.15	211.15	14.13	16.31	4.45	6.56	Yields, grams
80.18		244.00		−2.18		−2.11		B effects
−163.82				−0.07				P/B effects
−163.75/4 = −40.94								N/P/B effects
Root								
1,017.53	812.43	917.49	563.98	127.66	147.60	46.66	80.93	Yields, grams
205.12		353.51		−19.94		−34.27		B effects
−148.39				14.33				P/B effects
−162.72/4 = −40.68								N/P/B effects

*Data gram means of 8 pots.

at this particular set of three-way data. There are other equally valid ways, but as all lead to the same conclusion further exploration is redundant. The fact is the best yields were secured from the high N, high P, and high B levels, the other combinations following into the series $N^+P^+B^+ > N^+P^-B^+ > N^+P^+B^- > N^+P^-B^- > N^-P^+B^- > N^-P^+B^+ > N^-P^-B^- > N^-P^-B^+$, and suggesting that if nitrogen is low and boron deficiency is apparent, phosphorus should be increased as well as boron, whereas if nitrogen is high and boron deficiency develops, boron alone should be increased. Or conversely, when boron deficiency appears, it is probably wise to increase nitrogen simultaneously with boron, but not to increase phosphate.

DISEASE DATA

The estimation of the degree of deficiency symptoms was based on the following grade indices: 1, nil; 2, very slight; 3, slight; 4, fair; 5, medium; 6, severe; 7, rot set in; 8, severe rot; and 9, root dead.

In any grade system of estimation there is a tendency to subjective estimation and personal bias as opposed to the objective determination of a physical measurement. Nevertheless, in this work considerable effort was made to avoid subjective estimation of the deficiency symptoms. This was done by keying the samples by number and ignoring the key until all the estimates were completed. The validity of the estimates made is substantiated by the fact that in the analysis of the data in every case where boron was supplied the estimate of the degree of deficiency showed a decline in the disease symptom, which was not the case with the other elements considered.

The data reduced to mean grade indices per root for each nutrient treatment are given in Table 9, together with the associated mean

TABLE 9.—*Mean grade indices and related mean effects of boron-deficiency symptoms resulting from various nutrient levels on rutabagas.**

Nutrient levels†				Mean index	Mean effect	Nutrient factor
N	P	K	B			
−	−	−	−	4.4	4.5	O
+	−	−	−	6.5	−1.2**	N
−	+	−	−	4.0	−0.8**	P
+	+	−	−	6.3	1.1**	N P
−	−	+	−	8.7	1.8**	K
+	−	+	−	6.5	−1.4**	N K
−	+	+	−	6.8	−0.7**	P K
+	+	+	−	7.5	1.1**	N P K
−	−	−	+	3.0	−3.7**	B
+	−	−	+	1.0	−1.9**	N B
−	+	−	+	3.0	−0.5	P B
+	+	−	+	1.0	0.4	N P B
−	−	+	+	8.4	−0.3	K B
+	−	+	+	1.0	0.1	N K B
−	+	+	+	3.2	−0.6**	P K B
+	+	+	+	1.0	0.4	N P K B

*Data means of 3 plants × 4 pots.
**Denotes significance.
†+ = high level; − = low level.

effects for each of the nutrient factors and their interactions. The associated variance analysis is given in Table 5.

From these data it can be concluded that the four factors affected boron deficiency symptoms in a descending series as B> K> N> P; however, whereas boron, nitrogen, and phosphorus all tended to reduce the symptoms of the disease, potash distinctly increased them.

Several significant first-order interactions occurred, namely, NP, NK, PK, and NB. These are elaborated in detail in Table 10.

The NP interaction was positive, showing that nitrogen and phosphorus mutually reduced the effect of each other to control boron deficiency. Nitrogen tended to reduce the disease at either level of phosphorus, but more effectively at the lower level; phosphorus, however, reduced the disease when nitrogen was low, but slightly increased it when nitrogen was high.

TABLE 10.—*Details of the NP, NK, PK, and NB interactions with respect to grade indices of boron deficiency symptoms on rutabagas.**

Factor	Nitrogen		Across difference	Factor	Phosphorus		Across difference
Phosphorus	High	Low		Potash	High	Low	
High	4.0	4.2	−0.2	High	4.6	6.2	−1.6
Low	3.8	6.1	−2.3	Low	3.6	3.7	−0.1
Down difference	0.2	−1.9	Interaction 1.1	Down difference	1.0	2.5	Interaction −0.8

Factor	Nitrogen		Across difference	Factor	Nitrogen		Across difference
Potash	High	Low		Boron	High	Low	
High	4.0	6.8	−2.8	High	1.0	4.4	−3.4
Low	3.7	3.6	0.1	Low	6.7	6.0	0.7
Down difference	0.3	3.2	Interaction −1.5	Down difference	−5.7	−1.6	Interaction −2.1

*Data means of 3 plants × 16 pots.

The NK interaction was negative, showing nitrogen and potash mutually aided one another to reduce boron-deficiency symptoms. Potash tended to increase the disease greatly when nitrogen was low, slightly when nitrogen was high, while nitrogen had essentially no effect when potash was low, but was markedly effective at reducing the symptom when potash was high.

The PK interaction was similar to the NK interaction in that it was negative and indicated phosphorus and potash mutually aided one another to reduce the symptoms. Potash again increased the symptoms markedly when phosphate was low, slightly when it was high, while phosphorus reduced the disease slightly when potash was low, but markedly when it was high.

The NB interaction was also negative. Nitrogen slightly increased the symptoms when boron was low, but markedly reduced them when it was high. Boron, on the other hand, reduced the symptom at both levels of nitrogen, although more markedly when nitrogen was high.

There were two significant second-order interactions, NPK and PKB. These have been elaborated in Table 11.

TABLE 11.—*Details of the NPK and PKB interactions with respect to grade indices of boron deficiency symptoms.**

Nitrogen × Phosphorus × Potash

High potash				Low potash			
High P		Low P		High P		Low P	
High N	Low N	High N	Low N	High N	Low N	High N	Low N
4.3	5.0	3.8	8.5	3.7	3.5	3.8	3.7
−0.7		−4.7		0.2		0.1	
4.0				0.1			
3.9							

Phosphorus × Potash × Boron

High boron				Low boron			
High P		Low P		High P		Low P	
High K	Low K	High K	Low K	High K	Low K	High K	Low K
2.1	2.0	4.7	2.0	7.2	5.2	7.6	5.5
0.1		2.7		2.0		2.1	
−2.6				−0.1			
−2.5							

*Data means of 3 plants × 8 pots.

The NPK interaction was positive and indicates that nitrogen and phosphorus have little effect when potash is low, but the amount of of boron deficiency is low anyway. When potash is high, however, boron deficiency was severe, and both nitrogen and phosphorus reduced the disease, the former more than the latter, the latter actually inhibiting the effect of the former. So that when potash was high and nitrogen and phosphorus were low, boron deficiency was the greatest, and nitrogen alone effected greater control than either phosphorus alone or nitrogen and phosphorus together.

The PKB interaction was negative, indicating that potash was consistently deleterious regardless of the levels of phosphorus or boron. However, the amount of increase in deficiency symptoms effected by potash was markedly controlled by the respective levels of phosphorus and boron. Thus, phosphorus had little control upon the deleterious potash effect when boron was low, but a marked control when boron was high, and, conversely, boron was more effective in reducing the disease symptom when phosphorus was high.

DISCUSSION

One fact is paramount in these data, namely, that the efficacy of boron in increasing growth or decreasing the commonly understood symptoms of boron deficiency depends largely upon the relative proportions of nitrogen, phosphorus, and potash present, to name only three of the possible many factors which may control the growth of the plant.

Minarik and Shive (7) presented evidence that suggests that the influence of boron nutrition on the plant is intimately connected with the available calcium, and Saru (12) has suggested that there may also occur a potash × calcium × boron interaction. This being the case, it is rather obvious that the apparent confusion and contradictory results reported in minor element literature with regard to the boron nutrition of plants, as recently reviewed by Parks, Lyon, and Hood (8), might well be attributed to the restricted nature of the experiments conducted, involving, as they have, too few of the interrelating factors affecting boron nutrition.

For example, what we conceive as a boron-deficiency symptom can apparently arise from a variety of causes, one of which may be insufficient boron, depending upon the levels of the associated factors. Certainly the described symptoms of a calcium deficiency closely resemble those of a boron deficiency under certain conditions and in certain aspects (6). Precisely how many factors must be considered simultaneously and how they may actually integrate their relative effects in the growth of the plant can only be determined by further and more comprehensive experiments, but it is certain that isolating one factor at a time and varying that factor alone provides information of very restricted application, and therefore of questionable practical value.

The NPB interaction in the fresh-weight data of the entire plant provides material for some interesting speculation. Can boron, to a certain degree, replace phosphorus in the growth of some plants? Apparently in this case a larger plant can be procured from high nitrogen, low phosphorus, and high boron than from high nitrogen, high phosphorus, and low boron nutrition. Lack of phosphorus is evidently deleterious when boron is low, but of little consequence when boron is high. This situation, however, only prevails when nitrogen is high, for when it is low, boron cannot replace phosphorus and is actually toxic. Thus it would seem that nitrogen and boron are quite intimately related in their physiological function in the plant, and that phosphorus tends to enter the function and depress the complementary effect of nitrogen and boron. Briggs (1), studying the influence of boron nutrition in nitrogen metabolism in *Nasturtium*, has shown that the boron level in the substrate controls nitrogen absorption and its utilization.

Of course it is also possible that this NPB interaction on growth might show a different effect at another level of say calcium, magnesium, manganese, etc., however, it was evidently consistent over a wide range of potash levels, as there was no NPKB interaction.

It is apparent from the disease data herein presented that the incidence of boron deficiency in the plant was intimately connected

with the level of other nutritive factors besides boron. Of these factors nitrogen, phosphorus, and potash were of importance. Of these elements the relative effect that each had upon the development of boron-deficiency symptoms may be arranged in a descending series as K> N> P.

Potash tended to increase the disease, but whether it did so or not depended upon the level of the other factors, nitrogen and phosphorus. It is significant, however, that although nitrogen and phosphorus either separately or together did reduce this deleterious potash effect, boron did not reduce it. Boron may have neutralized it by its own effect, but as BK showed no significant interaction with respect to incidence of the disease, the BK effect was no more than what was to be expected from the B + K effects. This potash effect found its origin in something more substantial than a mere rate or amount of growth difference, as it appeared with greatest intensity when additional potash actually reduced plant size.

From the practical point of view it would seem advisable, therefore, to re-evaluate the potash components of mixed fertilizers which are to be applied to soils where boron deficiency is anticipated or known to exist, particularly for crops recognized as sensitive to inadequate boron nutrition.

The nitrogen effect on the disease symptom is extremely interesting in that it operates in one way—deleteriously—when boron was low, and in another—beneficially—when boron was high. This can possibly be explained by the "threshold" concept when boron was low, that is, the larger the plant became under the influence of nitrogen, the more likely it was to exhaust the low boron supply. However, when boron was high, this explanation fails, as nitrogen actually increased the efficacy of the boron. Perhaps this aspect can be explained by the "carbohydrate" effect discussed previously (13). Both lack of boron and of nitrogen will tend to increase carbohydrate in the foliage and addition of either will tend to reduce this condition, the best effect arising from the addition of both. This suggestion is substantiated by the different effects nitrogen and boron had on the roots and foliage with respect to fresh weight. Either boron or nitrogen increases roots differently to tops, but not as effectively as both together.

The phosphorus effect seems to have lain mostly in its growth effect. Phosphorus, however, reduced the deficiency even when growth was not increased. It seems that phosphorus, which is always regarded as so essential for rutabagas, owed its effect chiefly to the beneficial nitrogen effect which preceded it. Nitrogen was essential for foliage growth, and foliage was essential for root development; however, with nitrogen and with good foliage development, roots did not develop unless phosphorus was high also.

SUMMARY

1. Boron deficiency has been found to develop under field conditions even when applications of borax of recommended magnitude have been made.

2. Differential degrees of boron deficiency have been found on sus-

ceptible crops, associated with and apparently dependent on the nitrogen, phosphorus, and potash fertility levels employed.

3. The results of a factorial experiment conducted under greenhouse conditions, employing rutabaga as the test plant and involving two levels each of nitrogen, phosphorus, potash, and boron, are presented.

4. Nitrogen, phosphorus, and boron were found to have positive main effects upon growth. Potash had no main effect but showed a positive interaction with nitrogen. Boron also showed a positive interaction with nitrogen. Phosphorus, however, showed a negative interaction with boron. Nitrogen $\times$ phosphorus $\times$ boron was also a negative interaction in relation to growth.

5. Nitrogen, phosphorus, and boron all promoted root growth to a greater extent than foliage growth. Potash and boron each amplified the nitrogen effect.

6. Nitrogen, phosphorus, and boron all showed significant controlling main effects on the incidence of boron-deficiency symptoms in rutabaga, the order of efficacy being B> N> P. Potash showed a significant deleterious effect in this regard.

7. Nitrogen interacted with phosphorus to enhance the deficiency and with potash and boron to reduce it. Phosphorus interacted with potash and boron to reduce deficiency. Nitrogen, phosphorus, and potash mutually enhanced deficiency symptoms, but phosphorus, potash, and boron mutually reduced them.

LITERATURE CITED

1. BRIGGS, G. B. Effect of boron in the substrate on the rate of nitrogen absorption and on distribution in *Nasturtium*. Plant Phys., 18:415–432. 1943.
2. CHANDLER, F. B. Mineral Nutrition of the genus *Brassica* with particular reference to boron. Maine Agr. Exp. Sta. Bul. 404. 1941.
3. FISHER, R. A. The Design of Experiments. London: Oliver and Boyd. Ed. 2. 1938.
4. ————. Statistical Methods for Research Workers. London: Oliver and Boyd. Ed. 7. 1938.
5. HARTMAN, J. D. Boron deficiency of cauliflower and spinach on Long Island. Amer. Soc. Hort. Sci. Proc., 35:518–525:1938.
6. MCMURTREY, J. E., JR. Symptoms of field-grown tobacco characteristic of the deficient supply of each of several essential chemical elements. U. S. D. A. Tech. Bul. 612. 1938.
7. MINARIK, C. E. and SHIVE, J. W. The effect of boron in the substrate on calcium accumulation by soybean plants. Amer. Jour. Bot., 26:827–831: 1939.
8. PARKS, R. Q., LYON, C. B., and HOOD, S. L. Some effects of boron supply on the chemical composition of tomato leaflets. Plant Phys., 19:404–419. 1944.
9. POWERS, W. L., and BOUQUET, A. G. B. Use of boron in controlling canker of table beets. Ore. Agr. Exp. Sta. Circ. 213. 1940.
10. PURVIS, E. R., and HANNA, W. J. Boron studies: I. The susceptibility of various plants to boron toxicity as influenced by soil type. Soil Sci. Soc. Amer. Proc., 3:205–209. 1939.
11. REEVE, E., and SHIVE, J. W. Potassium—boron and calcium—boron relationships in plant nutrition. Soil Sci., 57:1–14. 1944.
12. SARU, N. The effect of boron on sugar beets. Kuhn-Arch., 48:1–51. 1939.
13. WHITE-STEVENS, R. H. Carbohydrate metabolism in relation to boron nutrition. Amer. Soc. Hort. Sci. Proc., 36: 537–543: 1939.
14. YATES, F. Complex experiments. Roy. Stat. Soc., 2:181–247. 1935.
15. ————. The design and analysis of factorial experiments. Imp. Bur. Soil. Sci. Tech. Com. 35:1937.

STRUCTURE OF HOUSTON BLACK CLAY AS REFLECTED BY MOISTURE EQUIVALENT DATA[1]

N. L. STOLTENBERG AND C. W. LAURITZEN[2]

NUMEROUS moisture equivalent determinations were made in obtaining characterizing data on the soils from the Blacklands Experimental Watershed at Waco, Texas. The interpretation of these data was difficult even though it was evident from observations that the moisture equivalent was closely related to the structure of the soil. Accordingly, additional centrifuge data were obtained to furnish information that might lead to a better interpretation of the moisture equivalent data. The data consist of results obtained from determinations of moisture equivalent made on samples of Houston black clay, consisting of natural clods and soil crushed to pass through 2-mm and 0.25-mm sieve openings, and these results supplemented by density determinations on the samples following centrifuging.

REVIEW OF LITERATURE

The term "structure" has been much used as a relative term to designate the general appearance of the soil, *viz*, crumb, granular, massive, etc. the term "structure" has also been loosely used at times almost synonymously with total porosity. It appears, however, that the distribution of effective pore size in percentage of volume of soil is the best index of soil structure. In recognition of its importance the size distribution of pore space in soil has been the subject of much recent investigation (1, 4, 5).[3]

Jamison (1) points out that two different processes are involved causing shifts in the size distribution of pore space in the soil; one relates to the formation and destruction of natural stable aggregates, and the other to factors that effect changes in the state of packing. It is evident that the stability of the aggregate is the characteristic chiefly responsible for distinguishing differences in pore size distribution in cultivated soil of similar composition.

Thomas and Harris (6) and others have pointed out that the structure of a soil may have a profound effect on the moisture equivalent. They have also shown that a maximum exists in the moisture equivalent-particle size at about 10 μ. They considered that the pore space remained full of water during the centrifuging at 1,000 gravity with particles of this size or smaller. It has been observed by the authors that water-stable aggregates of the Houston black clay broke into a very few particles when crushed. If the crushing is so done that there is the maximum number of larger particles consistent with the stability of the particles, and if these particles are appreciably larger than 10 μ, then the number of large particles and, consequently, the stability of these particles should be reflected in the macro pore space after centrifuging. The packing in the centrifuge should reduce the macro pore space to a minimum consistent with the number and size of the larger particles and the centrifugal force used.

Veihmeyer and associates (7) have determined that treating a soil by machine grinding, crushing with a roller, or grinding with a mortar and pestle, each gave higher and more variable moisture equivalents than using the method suggested here, that of crumbling and forcing through a 2-mm sieve with the fingers. They attributed these differences to "degree of pulverization".

---

[1]Contribution from the U. S. Dept. of Agriculture, Soil Conservation Service Blacklands Experimental Watershed, Waco, Texas. Received for publication May 15, 1944.

[2]Junior Soil Technologist and Associate Soil Technologist, respectively.

[3]Figures in parenthesis refer to "Literature Cited", p. 927.

METHODS AND PROCEDURE

Two areas of Houston black clay about 700 feet apart were selected for sampling. The soil in both areas was developed from the same geologic horizon. One area retained its virgin cover of native grasses and the other had been cultivated over 50 years, being utilized chiefly for the production of cotton and corn.

Four blocks of undisturbed soil were obtained from each area, two each at depths of 5 to 7 inches and at 11 to 13 inches. The removed blocks were actually somewhat larger but were subsequently cut to the depths as given. The water content of the soil at sampling is given in Table 1. A block of soil about 30 × 40 × 18 mm was cut from the center of each larger block, wrapped in a layer of facial tissue paper, placed on a cushion of fine sand in the moisture equivalent soil boxes in such a way that the surface facing the axis of the centrifuge was the upper surface when removed from the field, and the space around the block filled with fine sand. The samples thus prepared were allowed to stand in water for 18 hours so that the boxes were just covered, drained in a humidor 1 hour, centrifuged 40 minutes at 1,000 gravity, and placed in a humidor.

TABLE 1.—*Water content of soil sampling.*

Depth of sample, inches	Percentage water	
	Meadow	Cultivated
5–7	21	24
11–13	19	27

Each sample was removed in turn, quickly weighed, dipped in molten paraffin of known density, touched up with a warm glass rod to remove any air bubbles that might have formed, then reweighed. The volumes of the paraffined blocks were now determined by the water displacement method. The paraffin was then separated from the block and the soil dried at 110° C. and weighed. The pore space occupied by air and water was computed from the density of the uncoated samples after centrifuging, their water content and the specific gravity of the soil.

The soil removed from each block in obtaining the undisturbed samples was air dried and crushed in a mortar to pass a 2-mm sieve. Each sample was split and one half crushed to pass a 0.25-mm sieve (60 mesh). Care was taken in the crushing to use the minimum pressure necessary to get all particles to pass through the sieve used. The soil was crushed in small quantities with frequent sieving out of the fines. The 2-mm and 0.25-mm samples at both depths and from both locations were wetted and centrifuged in duplicate at 1,000 gravity for 40 minutes according to the usual procedure and their moisture contents determined. The apparent volume of one centrifuged sample from each location, each depth, and each size was determined by the paraffin method outlined above.

DISCUSSION OF RESULTS

Appreciable differences in structure of the meadow soil and the cultivated soil are readily observed, especially in the upper horizons, but the difference probably persists to depths of 2 feet or more. Data on the apparent volume and the relative permeability of the soils in the two areas are indicative of the differences which exist. The density of the clods from the meadow is appreciably lower (2) and apparently a greater percentage of the pore space in the meadow soil consists of larger pores, even neglecting root holes and animal burrows. Infiltration rates on cylinders of the meadow soil were higher and better sustained (3). Meadow clods appeared to have a more stable structure, breaking down to a lesser degree when placed in water than cultivated clods.

Field capacity-moisture equivalent ratios ranging from 0.74 to 1.24 were found for Houston black clay, the ratios usually decreasing with depth. These ratios were obtained using moisture equivalent data determined on samples passed through a 2-mm sieve. It is evident that ratios with a range of this magnitude make the moisture equivalent almost worthless as an index of field capacity. It is remarkable, however, that this ratio should be as constant as the figures indicate and data of others have shown it to be. Apparently the process of removing the soil and passing it through a 2-mm sieve changes the structure so as to compensate approximately for an increase in the force causing drainage of from 1 gravity to 1,000 gravity.

The moisture equivalent is completely determined by the percentage pore space retaining water, the percentage pore space devoid of water, and the specific gravity of the soil. It appears, therefore, that when samples are crushed, the structure, as defined above, and the stability of the structure are the primary factors affecting the moisture equivalent. Factors such as texture and compositional differences would affect the moisture equivalent only as they affect the structure and the specific gravity of the soil.

A simple moisture equivalent determination offers a convenient method of obtaining two points on the effective pore size distribution curve when the density of the samples after centrifuging and the specific gravity are known. For convenience the pore space retaining water after centrifuging in percentage of total volume will be designated the micro pore space, and that pore space devoid of water in percentage of total volume will be designated the macro pore space. The importance of the percentage of larger pores in controlling infiltration rates is recognized and it appears legitimate to use the macro pore space of undisturbed soil as an index of structure in considering infiltration.

The macro pore space in the undisturbed meadow soil at 6 inches averaged 12.8% for the two samples, while the undisturbed samples of cultivated soil averaged 8.4% at the same depth (Table 2). The macro pore space of the undisturbed samples at 12 inches is also appreciably greater in the meadow; however, variation between samples is greater. These differences are smaller than anticipated. Small differences, however, may become important, especially in considering infiltration.

It is interesting to compare the moisture equivalent of the 6 inch meadow samples with the 6 inch cultivated samples (Table 3). These had the same moisture equivalent when undisturbed and again almost the same when crushed to <2 mm. As evidenced by the moisture equivalent, the effect of crushing seems to be about the same in both the meadow and cultivated soil. However, crushing affected the pore space of the two soils quite differently, as indicated in Fig. 1. The macro pore space increased[4] from 12.3% to 33.2% of the total volume in the meadow soil, while the increase in the cultivated soil was only

[4]The comparison of differences due to treatment is based on differences obtained with material from the same block of soil rather than averaged values.

8.1% to 10.6%. The difference was even more striking after crushing to <0.25 mm. The macro pore space increased to 35.8% of the total volume in the meadow soil while there was a decrease to 6.1% in the cultivated soil.

TABLE 2.—*A comparison between the structure of Houston black clay in a cultivated field and in a meadow as evidenced by pore space percentage calculated from moisture equivalent data.*

Sample No.*	Soil Treatment	Sample depth, inches	Moisture equivalent	Density†	Specific gravity‡	Pore space—% total volume		
						Pore space	Micro pore space	Macro pore space
			Meadow					
1a	Undisturbed	6	31.0	1.258	2.64	52.3	39.0	13.3
2a	Undisturbed	6	29.9	1.293	2.64	51.0	38.7	12.3
3a	Undisturbed	12	26.4	1.430	2.65	46.0	37.8	8.2
4a	Undisturbed	12	27.2	1.395	2.65	47.4	38.0	9.4
1b	2 mm	6	36.3	—	2.64	—	—	—
2b	2 mm	6	36.4	0.899	2.64	66.0	32.7	33.2
3b	2 mm	12	33.1	—	2.65	—	—	—
4b	2 mm	12	33.2	0.962	2.65	63.7	31.9	31.8
1c	0.25 mm	6	44.4	—	2.64	—	—	—
2c	0.25 mm	6	46.2	0.764	2.64	71.1	35.3	35.8
3c	0.25 mm	12	43.8	—	2.65	—	—	—
4c	0.25 mm	12	44.4	0.813	2.65	69.3	36.1	33.2
			Cultivated					
5a	Undisturbed	6	30.1	1.357	2.69	49.6	40.8	8.8
6a	Undisturbed	6	30.9	1.349	2.69	49.8	41.7	8.1
7a	Undisturbed	12	29.8	1.388	2.70	48.6	41.4	7.2
8a	Undisturbed	12	29.2	1.411	2.70	47.7	41.2	6.5
5b	2 mm	6	36.0	—	2.69	—	—	—
6b	2 mm	6	36.0	1.222	2.69	54.6	44.0	10.6
7b	2 mm	12	36.6	1.230	2.70	54.4	45.0	9.4
8b	2 mm	12	—	—	2.70	—	—	—
5c	0.25 mm	6	51.3	—	2.69	—	—	—
6c	0.25 mm	6	48.4	1.097	2.69	59.2	53.1	6.1
7c	0.25 mm	12	50.0	1.103	2.70	59.1	55.1	4.0
8c	0.25 mm	12	52.4	—	2.70	—	—	—

*Samples with the same numeral designation represents material from the same block of soil.
†Grams per cc.
‡Average of a number of samples taken nearby.

This increase in macro spore space in the meadow soil between the 2-mm and the 0.25-mm sizes indicates that the effect of aggregates breaking down to give effective pore sizes greater than 10μ was larger than the effect of those breaking down to give pore spaces less than 10μ. In the cultivated soil the decreases in macro pore space indicate

the reverse to be true. In line with previous discussion it is suggested that the values of macro pore space after crushing to 0.25 mm when

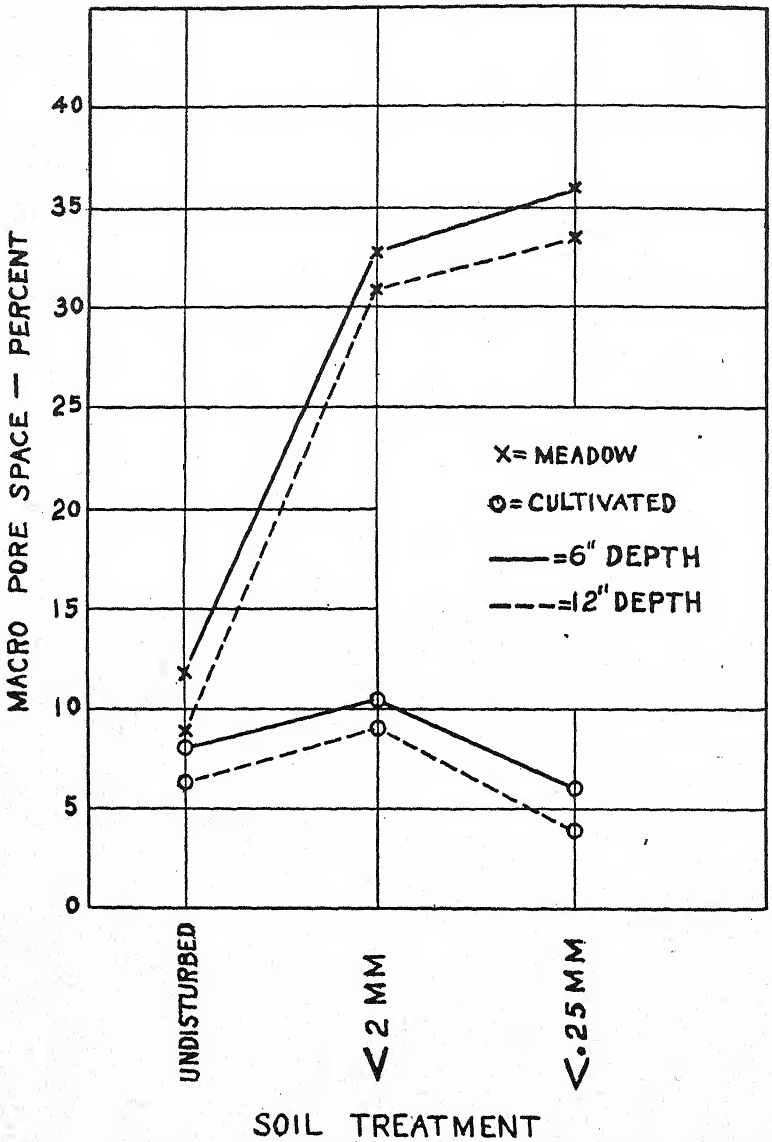


FIG. 1.—The effect of crushing on the macro pore space in samples of two soils.

compared with the values for the undisturbed samples can be used as an index of the aggregate or structural stability. The data, therefore, indicate that not only was the structure of the meadow soil such

TABLE 3.—*The effect of breaking up undisturbed samples of Houston black clay on the moisture equivalent.**

Soil treatment	Moisture equivalent			
	Meadow, 6 in.	Meadow, 12 in.	Cultivated, 6 in.	Cultivated, 12 in.
Undisturbed..........	30.5	26.8	30.5	29.5
<2 mm..............	36.3	33.2	36.0	36.6
<0.25 mm...........	45.3	44.1	49.8	51.2

*Values for undisturbed soil are the mean of two samples. Values for sieved soil are the mean of two samples run in duplicate.

as to have a greater percentage of macro pore space, but also that the stability of this structure was greater.

The importance of standardizing the preparation of samples for determining the moisture equivalent is emphasized by the data presented in Table 3. While these data furnish only indirect evidence as to the particle size, it is a common observation that the dustiness, and therefore probably the mean particle size, is affected by the moisture content when crushed. The method of crushing as outlined by Veihmeyer (7) is considered to be satisfactory, but it is further suggested that the crushing be done on moist soil in the semi-solid state slightly below the lower plastic limit.

SUMMARY

The relation between the structure and stability of structure of Houston black clay and the moisture equivalent is discussed, and comparisons made between samples from a meadow and a cultivated field.

It has been concluded that the moisture equivalent of Houston black clay is primarily dependent on the structure of the soil in its undisturbed state and the stability of that structure during the breaking up to pass a 2-mm sieve. The meadow soil was found to be aggregated better and the aggregates had a greater stability.

The importance of the manner and degree of crushing of the soil prior to a moisture equivalent determination is again pointed out.

LITERATURE CITED

1. JAMISON, VERNON C. Structure of a Dunkirk silty loam in relation to pF moisture measurements. Jour. Amer. Soc. Agron., 34:307–321. 1942.
2. LAURITZEN, C. W., and STEWART, A. J. Soil-volume changes and accompanying moisture and pore space relationships. Soil Sci. Soc. Amer. Proc., 6:113–116. 1942.
3. ———— and STOLTENBERG, N. L. Some factors which influence infiltration and its measurement in Houston black clay. Jour. Amer. Soc. Agron., 32:853–866. 1940.
4. LEAMER, R. W., and LUTZ, J. F. Determination of pore size distribution in soils. Soil Sci., 49:347–360. 1940.
5. RUSSELL, M. B. Soil moisture sorption curves for four Iowa soils. Soil Sci. Soc. Amer. Proc., 4:51–54. 1940.
6. THOMAS, M. D., and HARRIS, KARL. The moisture equivalent of soils. Soil Sci., 21:411–424. 1926.
7. VEIHMEYER, F. J., ISRAELSEN, O. W., and CONRAD, J. P. The moisture equivalent as influenced by the amount of soil used in its determination. Univ. Calif. Col. Agr. Tech. Paper 16. 1924.

RESPONSE OF WHEAT VARIETIES TO APPLICATIONS OF SUPERPHOSPHATE FERTILIZER[1]

L. P. Reitz and H. E. Myers[2]

WINTER wheat when grown on upland soil in the eastern one fourth of Kansas usually has responded favorably to applications of phosphate fertilizer (6, 7).[3] As information was desired on the reactions that different varieties of wheat might show, an experiment was outlined to obtain it. The present paper is a report on the results obtained over a period of 8 years, 1931 to 1938, at Manhattan, Kans., on Geary silt loam soil.

REVIEW OF LITERATURE

Several experiments testing the differential effect of fertilizers on small grain varieties have been reported upon from other states. Lamb and Salter (4) found with 17 varieties of oats grown on four fertility levels over a 4-year period at the Ohio Agricultural Experiment Station that the variety-level interaction of oats probably was not significant. The same authors (3) found a significant variety-level interaction in a study of 11 wheat varieties grown at four fertility levels for five seasons and concluded that wheat varieties respond differently to a series of fertility levels.

Lamb and Bayfield (2) tested 10 varieties of wheat grown at 15 locations in Ohio during four seasons. In yield of grain, weight per bushel, protein content of the grain, and wheat ash, nonsignificant variety-location interactions were obtained. The locations represented widely different soil types.

Worzella (8) tested five varieties of wheat on three levels of soil fertility on each of three soil types in Indiana during a 5-year period. He concluded that, "while the variety × fertility level interactions for grain yield are significant, the interactions are not great enough to change yield ranks".

MATERIALS AND METHODS

Three varieties of winter wheat, Turkey, Tenmarq, and Quivira, representing late, medium, and early maturity, respectively, were grown in each of the years 1931 to 1938, inclusive. An early, unnamed hybrid selection from the cross Kanred × Hard Federation (C.I. 10092) was included during the years 1936 to 1938, inclusive.

Each variety was grown in 12 plots each year. Six of the plots were treated with 16% superphosphate fertilizer at the rate of 200 pounds per acre applied in the row with the seed, while the other six plots were untreated. While the actual arrangement of plots varied slightly from year to year, analysis was possible on the basis of six blocks in which a block contained each variety in treated and untreated plots. Briefly then, the experiment consisted of three or four varieties grown in six replications with two treatments in each of eight years.

The plots were grown on different blocks of land each year on soil now classified as Geary silt loam. This soil, as described by Metzger (5), is a moderately leached soil developed under a grass cover, with dark to very dark brown, loose,

---

[1]Contribution No. 360. Department of Agronomy, Kansas Agricultural Experiment Station, Manhattan, Kans. These experiments were planned by F. L. Duley, formerly Professor of Soils, and John H. Parker, formerly Professor of Crop Improvement, conducted by F. L. Duley from 1931 to 1933 and by the late W. H. Metzger, formerly Associate Professor of Soils, from 1934 to 1938. The authors gratefully acknowledge their contributions to this research. H. C. Fryer, Statistician, assisted with the statistical analyses. Received for publication July 20, 1944.

[2]Associate Agronomist and Agronomist, respectively.

[3]Figures in parenthesis refer to "Literature Cited", p. 936.

friable, and weakly granulated surface soil with reddish brown, moderately compact subsoil. In the first year the plots were 6 feet wide by 29 feet long planted with a farm drill with a fertilizer attachment, but in the other years the plots were 7 by 12½ feet and were cared for entirely by hand methods. The preceding crop was a uniform planting either of oats or wheat.

The yield of grain was determined each year; protein content and straw weights were recorded in 7 years; test weight and other grain notes were recorded in 5 years; maturity, height, and lodging notes were taken in 1 to 4 years of the testing period.

Weather conditions were variable from year to year. The average annual precipitation at Manhattan is 30.97 inches. The precipitation received in each crop year ending with June 30 from 1931 to 1938, inclusive, was 25.91, 38.66, 19.35, 23.25, 27.93, 30.16, 25.86, and 26.86 inches, respectively. Mean annual temperatures were above normal during the period (1).

The weather conditions for wheat at Manhattan can be characterized more precisely by the total rainfall received between March 1 and the maturity date in June and by the temperature in May and June, especially the frequency of days when the maximum temperature was 95° F or higher. The rainfall for this period for the years 1931 to 1938, inclusive, was 10.51, 6.71, 6.24, 5.68, 15.67, 8.17, 8.08, and 14.09 inches respectively. Hence, when the wheat was making its most rapid growth and was producing grain, moisture was least in 1932, 1933, and 1934 and greatest in 1935 and 1938. The average temperature for May and June was lowest in 1935 and highest in 1934; 1933 and 1936 had temperature averages below 1934 but were 2 or 3 degrees warmer than the other years which approached the normal for this station. A maximum temperature of 95° F or above was recorded in May and June, before the wheat ripened, on 2 days in 1931, 10 days in 1933, 11 days in 1934, 13 days in 1936, 6 days in 1937, and 1 day in 1938, and not at all in 1932 or 1935.

EXPERIMENTAL RESULTS

Annual and average yields of grain produced by the varieties with and without fertilizer are shown in Table 1. In all cases, applications of phosphate increased yields of grain from 7.3% to 84.2%. In the 8-year period, the average yield of Turkey was increased 37.0%, of Tenmarq 33.4%, and of Quivira 26.4%. In the period of 3 years, 1936 to 1938, Turkey and Tenmarq were increased 28.6% and 29.4%, respectively, while Quivira was increased 24.7% and Kanred × Hard Federation 20.0%. The greatest relative increases occurred in 1933, a very dry year, with an especially dry hot June. The least response was in 1937, a moderate year for weather except for a drought in April and early May and a dry period just as the wheat was ripening.

Quivira gave the highest average yield from both treated and untreated plots followed in order by Tenmarq and Turkey. The relative increase was less for Quivira than for the other varieties under comparison for 8 years. Kanred × Hard Federation gave the least response among the comparisons for the 3-year period.

Yields of grain were studied statistically by analysis of variance. Significance of yield differences indicated by the analysis is shown in Tables 2 and 3. The varieties gave significantly different yields in 5 of the 8 years and for the average of the period. Fertilizer gave significantly higher yields each year on all varieties. The variety × fertilizer interaction was significant at the 1% level only in 1932 and reached the 20% level in 1931 and 1935. In every year except 1936, Turkey showed greater percentage response to fertilizer than Quivira and Tenmarq, but the differences were not great enough to be statistically significant except as noted above. Trends for the four

TABLE 1.—*Average yields of grain in bushels per acre produced by four varieties of winter wheat and increases resulting from superphosphate application, 1931–38.*

Treatment	1931	1932	1933	1934	1935	1936	1937	1938	8-yr. av.	3-yr. av.
Turkey										
Superphosphate	38.64	44.52	26.36	19.44	32.29	24.40	39.71	19.13	30.56	27.75
Check	29.49	32.21	14.31	15.17	22.54	16.13	33.76	14.84	22.31	21.58
Increase from fertilizer										
Bushels	9.15	12.31	12.05	4.27	9.75	8.27	5.95	4.29	8.25	6.17
Per cent	31.0	38.2	84.2	28.2	43.3	51.3	17.6	28.9	37.0	28.6
Tenmarq										
Superphosphate	42.03	46.71	25.10	21.40	33.27	23.40	39.95	26.90	32.35	30.08
Check	34.37	33.79	14.39	18.05	23.68	13.06	34.16	22.86	24.25	23.25
Increase from fertilizer										
Bushels	7.66	12.92	10.71	3.35	9.59	10.34	5.79	4.04	8.10	6.83
Per cent	22.3	38.2	74.4	18.6	40.5	79.2	16.9	17.7	33.4	29.4
Quivira										
Superphosphate	48.41	41.31	25.31	31.80	28.49	22.76	43.08	28.03	33.65	31.29
Check	37.20	35.73	15.98	25.91	22.90	14.78	37.51	22.98	26.62	25.09
Increase from fertilizer										
Bushels	11.21	5.58	9.33	5.89	5.59	7.98	5.57	5.05	7.03	6.20
Per cent	30.1	15.6	58.4	22.7	24.4	54.0	14.9	22.0	26.4	24.7
Kanred×Hard Federation										
Superphosphate	—	—	—	—	—	18.36	44.10	19.81	—	27.42
Check	—	—	—	—	—	13.16	36.97	18.46	—	22.86
Increase from fertilizer										
Bushels	—	—	—	—	—	5.20	7.13	1.35	—	4.56
Per cent	—	—	—	—	—	39.5	19.3	7.3	—	20.0

TABLE 2.—*Analysis of variance of annual winter wheat grain yield data.*

Source of variation	D/F	Mean squares							
		1931	1932	1933	1934	1935	1936	1937	1938
Total	35	—	—	—	—	—	—	—	—
Variety (3)	2	229.60**	13.20†	3.54	445.23**	23.67*	13.33	46.58*	270.31**
Fertilizer	1	785.15**	949.56**	1029.60**	182.48**	621.50**	706.67**‡	299.52**	179.11**
Variety × fertilizer	2	24.06†	49.74**	5.87	4.94	16.72†	4.94	0.11	0.84
Between block	5	17.01	7.07	10.56	31.30†	4.62	112.15**	18.95	2.22
Remainder (error)	25	12.04	4.88	110.46	14.46	6.70	9.38	8.44	3.80
Total	47	—	—	—	—	—	—	—	—
Variety (4)	3	—	—	—	—	—	42.15**	49.91**‡	213.26**
Fertilizer	1	—	—	—	—	—	757.23**‡	448.11**‡	162.77*
Variety × fertilizer	3	—	—	—	—	—	13.39	1.48	7.82†
Between block	5	—	—	—	—	—	117.74**	22.22*	2.76
Remainder (error)	35	—	—	—	—	—	8.75	8.68	2.92

*Significant at the 5% point.
**Significant at the 1% point.
†Significant at the 20% point.
‡Significant if block variability is included in error.

TABLE 3.—*Analysis of variance of average winter wheat grain yield data.*

Source of variation	1931–38, 3 varieties		1936–38, 4 varieties	
	D/F	Mean squares	D/F	Mean squares
Total	287	—	143	—
Seasons	7	2,759.14***	2	5,739.09***
Variety	2	329.08**	3	92.58**
Fertilizer	1	4,354.62***	1	1,258.48***
Season × variety	14	102.20**	6	106.37**
Season × fertilizer	7	57.11*	2	54.82**
Variety × fertilizer	2	10.43	3	7.90
Season × variety × fertilizer	14	11.70	6	7.40
Block within seasons	40	25.53	15	47.57**
Remainder	200	21.41	105	6.78

*Significant at the 5% point. **Significant at the 1% point. ***Significant at the 0.1% point.

TABLE 4.—*Average yields of straw in tons per acre produced by four varieties of winter wheat and increases from applications of superphosphate fertilizer, 1932–38.*

Treatment	1932	1933	1934	1935	1936	1937	1938	7-yr. av.	3-yr. av.
Turkey									
Superphosphate	2.90	2.11	1.87	1.83	1.98	2.20	1.58	2.07	1.92
Check	2.05	1.60	1.79	1.27	1.53	2.00	1.39	1.66	1.64
Increase from fertilizer									
Tons	0.85	0.51	0.08	0.56	0.45	0.20	0.19	0.41	0.28
Per cent	41.5	31.9	4.5	44.1	29.4	10.0	13.7	24.7	17.1
Tenmarq									
Superphosphate	2.59	2.19	1.82	1.62	1.69	1.95	1.81	1.95	1.82
Check	1.86	1.63	1.67	1.18	1.49	1.71	1.57	1.59	1.59
Increase from fertilizer									
Tons	0.73	0.56	0.15	0.44	0.20	0.24	0.24	0.36	0.23
Per cent	39.3	34.4	9.0	37.3	13.4	14.0	15.3	22.6	14.5
Quivira									
Superphosphate	2.22	2.20	2.04	1.51	1.71	2.07	1.88	1.95	1.89
Check	1.76	1.57	1.69	1.10	1.41	1.79	1.53	1.55	1.58
Increase from fertilizer									
Tons	0.46	0.63	0.35	0.41	0.30	0.28	0.35	0.40	0.31
Per cent	26.1	40.1	20.7	37.3	21.3	15.6	22.9	25.8	19.6
Kanred × Hard Federation									
Superphosphate	—	—	—	—	1.51	2.13	1.59	—	1.74
Check	—	—	—	—	1.32	1.78	1.39	—	1.50
Increase from fertilizer									
Tons	—	—	—	—	0.19	0.35	0.20	—	0.24
Per cent	—	—	—	—	14.4	19.7	14.4	—	16.0

TABLE 5.—*Analysis of variance of annual winter wheat straw yield data.*

Source of variation	D/F	Mean squares						
		1932	1933	1934	1935	1936	1937	1938
Total	35	—	—	—	—	—	—	—
Variety	2	0.7188**	0.0096	0.0459	0.1814**	0.1376*	0.2240*	0.1801**
Fertilizer	1	4.2278***	2.8991**	0.3291**	2.0022***	0.8849**	0.5239**	0.6131**
Variety × fertilizer	2	0.1180**	0.0116	0.0594	0.0502*	0.0456	0.0053	0.0186
Between blocks	5	0.0302	0.0646	0.0388	0.0296	0.3263**	0.1890	0.0095
Remainder (error)	25	0.0205	0.0799	0.0272	0.0144	0.0300	0.0632	0.0127
Total	47	—	—	—	—	—	—	—
Variety	3	—	—	—	—	0.2350**	0.1493*	0.1770**
Fertilizer	1	—	—	—	—	0.9456**	0.8665**	0.7245**
Variety × fertilizer	3	—	—	—	—	0.0434	0.0126	0.0152
Between blocks	5	—	—	—	—	0.3997**	0.1981**	0.0109
Remainder (error)	35	—	—	—	—	0.0297	0.0521	0.0121

*Significant at the 5% point.
**Significant at the 1% point.
***Significant at the 0.1% point.

varieties grown from 1936 to 1938 were similar to those for the longer period.

Annual and average yields of straw are shown in Table 4. In every case, applications of phosphate increased straw production with the greatest increase in 1935 and least in 1937. Percentage response of the varieties was similar on the average. Analysis of variance showed that significant differences were obtained between varieties and treatments but that the variety × fertilizer interaction was nonsignificant on the average and was significant only in 1932 and 1935, 2 of the 3 years when grain differences were significant (Tables 5 and 6).

TABLE 6.—*Analysis of variance of total winter wheat straw yield data.*

Source of variation	1932–38, 3 varieties		1936–38, 4 varieties	
	D/F	Mean squares	D/F	Mean squares
Total	251	—	143	—
Seasons	6	2.5207***	2	2.1703***
Variety	2	0.3255**	3	0.1657**
Fertilizer	1	9.5940***	1	2.5289***
Season × variety	12	0.1953**	6	0.1978**
Season × fertilizer	6	0.3143**	2	0.0038
Variety × fertilizer	2	0.0077	3	0.0110
Season × variety × fertilizer	12	0.4039**	6	0.2346**
Block within seasons	35	0.0983**	15	0.2029**
Remainder	175	0.0112	105	0.0196

*Significant at the 5% point.
**Significant at the 1% point.
***Significant at the 0.1% point.

Other measured effects of the treatments and results obtained are shown in Table 7. Applications of phosphate hastened maturity on all varieties from ½ day to 3 days. There was a trend toward greater hastening of maturity of the early maturing varieties, but this could not be established with the data available.

The test weight per bushel was greater for phosphate-treated plots than for the check plots by 0.8 to 1.6 pounds to the bushel. No varietal trend was apparent.

In general, protein content per unit of grain was lower on phosphate-treated plots than on the check plots. Actually, more protein was produced per acre on the fertilized plots, owing to the much greater total grain yield from these plots. During the last 3 years of the test, Tenmarq and Kanred × Hard Federation were higher on the phosphated plots. These data support other data (unpublished) that show the Kanred × Hard Federation selection produces a lower protein content than most other varieties in its class.

Average height of plants was increased by phosphate applications in most cases. Average increases ranged from a fraction of an inch to 3 inches. This accounts in part for the greater yields of straw harvested from fertilized plots. There was no consistant effect on lodging. The percentage of yellowberry grain was recorded in each of 5 years with little or no differences noted for fertilizer treatment except in 1935 when more yellowberry showed in grain from fertilized plots and less yellowberry in the Quivira variety.

TABLE 7.—*Average dates of maturity, test weights per bushel, and protein content for four varieties of winter wheat and differences resulting from applications of superphosphate fertilizer.**

Treatment	Dates of maturity in June		Test weight per bushel, lbs.		Protein content, %	
	4-yr. av., 1934–37	2-yr. av., 1936–37	5-yr. av., 1934–38	3-yr. av., 1936–38	7-yr. av., 1931–32, 1934–38	3-yr. av., 1936–38
			Turkey			
Superphosphate......	22.3	23.8	58.3	58.0	13.46	13.44
Check..............	22.8	24.8	57.5	56.9	13.84	13.77
Difference...........	−0.5	−1.0	0.8	1.1	−0.38	−0.33
			Tenmarq			
Superphosphate......	21.4	23.6	58.0	57.2	13.35	13.36
Check..............	22.8	25.1	56.7	55.6	13.63	12.98
Difference...........	−1.4	−1.5	1.3	1.6	−0.28	0.38
			Quivira			
Superphosphate......	18.6	20.3	60.4	59.5	13.63	13.83
Check..............	20.3	23.3	59.3	85.2	14.00	13.91
Difference...........	−1.7	−3.0	1.1	1.3	−0.37	−0.08
			Kanred × Hard Federation			
Superphosphate......	——	21.6	——	57.5	——	12.71
Check..............	——	23.6	——	56.2	——	12.55
Difference...........	——	−2.0	——	1.3	——	0.16

*A minus denotes lower values for fertilized plots.

DISCUSSION

The results of this experiment tend to confirm the work reported by other investigators and indicate that when varieties of similar adaptation are tested, all tend to respond to fertilizers in a similar manner. When varieties differ rather markedly, one may expect a differential response. Variable effects of fertilizer may be expected also when the seasons affect different varieties differently. Thus a late variety might benefit from the earlier maturity usually associated with phosphate treatment, whereas an early variety might not be benefitted. With the varieties studied, phosphate was beneficial to all and statistically significant differences do not show in an average of several years.

The variety-fertilizer interaction was highly significant in 1932. This season was relatively cool and dry in which both Turkey and Tenmarq were benefitted more by the fertilizer than was Quivira. In 1931 and 1935 this interaction showed slight significance. The season in 1931 was relatively cool but quite favorable in precipitation, and Turkey and Quivira responded to fertilizer more than Tenmarq. The 1935 season was cool and wet with conditions favorable for leaf rust development. Turkey, a variety susceptible to leaf rust, showed more

response than Quivira, a semi-resistant variety. The same trend of response was shown in 1937 and 1938 when rust was again abundant. Tenmarq gave intermediate or lower response in these two years.

Throckmorton and Duley (7), working with one variety, reported effects of phosphate almost identical with those observed here. Their tests covered the years 1911 to 1930 and showed that applications of superphosphate to wheat gave higher grain yields, higher test weight, more yellowberry, and lower protein content. Plant height was not affected consistently.

The specific physiological benefits of phosphate treatment are difficult to assign. When the yield is increased and the maturity date is changed, marked differences in physiological activity and efficiency must occur. Phosphate application helps to balance the needs of wheat for nutrients on this soil, and in so doing improves the conditions for plant growth. In turn, this would influence root extension, and leaf, stem, and seed formation, enabling the plants to perform normal processes more efficiently. With earlier maturity there is normally less exposure to adverse weather conditions and partial escape from rust and other hazards.

SUMMARY

An experiment was conducted to determine if different varieties of winter wheat respond differently to applications of superphosphate.

Three varieties, Turkey, Tenmarq, and Quivira, were compared from 1931 to 1938, inclusive; a fourth variety was included during the last 3 years of this period.

Applications of phosphate fertilizer gave increased yields of grain and straw, increased test weight slightly, increased percentage of yellowberry grains, reduced protein content of the grain, and hastened maturity. The varieties gave significantly different yields of grain.

The variety-fertilizer interaction for grain yield was significant at the 1% level in 1932 and at the 20% level in 1931 and 1935 but was not significant for the entire period. Varieties of similar adaptation tend to give equal response to applications of phosphate fertilizer.

LITERATURE CITED

1. CARDWELL, A. B., and FLORA, S. D. The climate of Kansas. Kans. Agr. Exp. Sta. Bul. 203. 1942.
2. LAMB, C. A., and BAYFIELD, E. G. The influence of season and location on the grain of several wheat varieties. Jour. Amer. Soc. Agron., 33:294–303. 1941.
3. ———— and SALTER, R. M. Response of wheat varieties to different fertility levels. Jour. Agr. Res., 53:129–143. 1936.
4. ————, ————. Response of oat varieties to different fertility levels. Jour. Agr. Res., 55:785–793. 1937.
5. METZGER, W. H. Nitrogen and organic carbon of soils as influenced by cropping systems and soil treatments. Kans. Agr. Exp. Sta. Tech. Bul. 45. 1939.
6. THROCKMORTON, R. I., and DULEY, F. L. Soil fertility. Kans. Agr. Exp. Sta. Bul. 260. 1932.
7. ————, ————. Twenty years of soil fertility investigations. Kans. Agr. Exp. Sta. Tech. Bul. 40. 1935.
8. WORZELLA, W. W. Response of wheat varieties to different levels of soil productivity. Jour. Amer. Soc. Agron., 35:114–124. 1943.

NOTES

AFTERNOON VS. MORNING CUTTING OF ALFALFA

THE gains for afternoon cutting of alfalfa reported in recent articles by O. F. Curtis[1] seem to the writer to be too good to be true. Whether or not his conclusions are valid will finally be decided by additional data, which the writer has not been in a position to obtain. There is evidence now available, however, which should at least give pause before we promise farmers a quarter of a ton more hay, containing nearly double as much sugar and starch, for cutting hay in the afternoon instead of in the morning.

It is generally accepted that there is *more* sugar and starch in the leaves of any ordinary plant in the late afternoon than in the early morning. Hence, the questions raised by these articles are: (1) How much more dry matter is present in the evening than in the morning? (2) What happens to this extra sugar and starch during ordinary hay curing?

In studies by the writer and associates[2] on alfalfa production in Ohio, only a few net increases as great as 150 pounds of hay per acre per day were obtained—most of them were under 100 pounds.

Thomas and Hill,[3] to whom Curtis refers, have made the most accurate quantitative study of photosynthesis and respiration in alfalfa known to the writer. They report nine experiments over a total of 279 days, conducted under irrigation in Utah, with soil and weather conditions more favorable for growth of alfalfa than in the humid East. The average of these nine experiments, calculated to pounds per acre, was a gross increase in dry matter of 272 pounds per acre per day, and a respiration at night of about 32 pounds of dry matter, leaving a net increment of 240 pounds per acre per day. Of this, an average of 75 pounds was recoverd in the tops, and an average of 165 pounds was assumed to have been translocated to the roots.

None of these average figures for daily increment of alfalfa come very close to the 512 pounds per acre reported by Curtis. Even the largest single day's dry matter accumulation out of the 279 reported by Thomas and Hill, quoted by Curtis, lacks nearly 100 pounds of equaling Curtis' *average*.

However, let us assume for a moment that 512 pounds of dry matter per acre per day are produced from morning to evening. What could

[1]CURTIS, OTIS F. The food content of forage crops as influenced by the time of day at which they are cut. Jour. Amer. Soc. Agron., 36:401–416. 1944.
———— and WASLIEN, P. J. Diurnal changes in the food content of hay and other crops. Amer. Jour. Bot., 29:65. 1942.
————. Better hay from late afternoon mowing. Amer. Agr., 140: No. 14, July 3, 331–332. 1943.
————. The food content of forage crops as influenced by the time of day at which they are cut. Mimeographed, June 14, 1943.

[2]WILLARD, C. J., THATCHER, L. E., and CUTLER, J. S. Alfalfa in Ohio. Ohio Agr. Exp. Sta. Bul. 540. 1934.

[3]THOMAS, MOYER D., and HILL, GEO. R. The continuous measurement of photosynthesis, respiration, and transpiration of alfalfa and wheat growing under field conditions. Plant Phys., 12:285–307. 1937.
———, ———. The relation of sulphur dioxide in the atmosphere to photosynthesis and respiration in alfalfa. Plant Phys., 12:309–383. 1937.

become of it? The average yield of hay in the morning in Curtis' data is only 2,700 pounds per acre (calculated from his statement that 512 pounds is a 19% increase in yield), so that 150 pounds would be an excessive amount to allow for net daily increase in dry matter for an end point of 2,700 pounds. This would leave at least 362 pounds of material per acre per day out of the 512 that must disappear from the tops in some way. (Disappearances even greater than 362 pounds should be accounted for, since, over a harvest period extending from June 10 to June 25, with average gross gains on each day of over 500 pounds per acre, Curtis reports no increase in the total yield of the field. The explanation is made that different areas were used for each harvest, but even so, one would expect some increase in hay yields if the recorded daily gains were real.)

There are three ways in which significant amounts of material might disappear from the tops overnight, *viz.*, mechanically (dropping of leaves and leaves eaten by insects), by translocation to the roots, and by respiration. While there is considerable total mechanical loss of leaves, as has been shown by every study of the time of cutting alfalfa, the amount of this loss in 12 to 15 night hours would be so small that it could not account for more than a tiny fraction of 500 pounds per acre.

In the writer's studies of the growth of alfalfa roots under humid conditions, the largest net increment in dry weight that he has ever recorded, under exceptionally favorable conditions for root storage, was 40 pounds per acre per day. This was in the top foot of soil only, but under Ohio conditions[4] this represents at least half of the total root system. Thomas and Hill's data, just quoted, indicate much larger amounts of translocation to the roots, but alfalfa roots grow much larger and deeper in Utah under irrigation than in the humid East.

If the largest increment we have obtained is doubled and Thomas and Hill's average figure for respiration (32 pounds) added to it to allow for respiration of the roots, we have a total of about 112 pounds per acre per day as probably the maximum amount of material that can be accounted for by transfer to the roots. This leaves at least 250 pounds per acre per day out of the 512 reported by Curtis, or about 8 times Thomas and Hill's average figure, to be accounted for by respiration. There seems to be no reasonable way in which a dry matter production of 512 pounds per acre per day can be accounted for.

Furthermore, Curtis' analytical data indicate that only 95 pounds of this 512 is sugar and starch. The other 417 pounds, therefore, must have already been built up into plant tissue by evening. Surely such materials are not translocated to the roots, or respired. Why then do they not show up as a daily 417-pound per acre gain in yield?

In the humid East, it is very difficult to maintain sufficient reserves of food materials in the roots.[5] If cutting alfalfa in the morning really added greatly to its root reserves, most agronomists would consider the practice a desirable one for that reason.

[4]See footnote 2, page 141.
[5]See footnote 2, page 118.

Can ordinary curing methods take advantage of the fact that more starch and sugar are present in forage in the afternoon? Suppose half of a field is cut late in the afternoon and the other half the next morning. With ordinary curing, how much difference will there be in the hay from the two areas? No reason has been suggested why cut, unwilted, forage should respire less than uncut forage. Consequently, the only apparent reason for a difference in amount or composition is translocation of material from the standing alfalfa to the roots. This, as just noted, is a small amount, and really a gain to the alfalfa grower. Curtis makes this comparison in treatments 5 and 6, but his results are so variable that they are not conclusive. Unless there is significantly less respiration in the cut than in the standing forage, only the man who artificially dries his hay or puts it in the silo at once can profit by the greater sugar content of hay cut in the afternoon.

The writer believes the following statements are justified: (1) There is much reason to believe that the maximum difference in dry matter in a stand of alfalfa between morning and evening in the humid East is of the order of 250 pounds per acre instead of 500, and that the average difference is much less than this. (2) The farmer who does not artificially dry his hay at once or put it in the silo at once cannot capitalize on this difference, since the most important source of loss, respiration, probably goes on in both cut and uncut forage at the same rate. Cutting in the evening would prevent one day's translocation to the roots, but this translocation is a gain to the stand and is seldom over 50 pounds per acre per day in this region.

Neither of these statements is finally established, but the writer believes that the evidence for them outweighs a few averages of nine 1-square-foot samples. In taking many thousands of square-yard samples of alfalfa and alfalfa mixtures, the writer has had first-hand experience with their possible variability. It is not unusual for a single stem of alfalfa to weigh 2 grams. Curtis' samples weighed from 26 to 40 grams, so that in placing the frame he used, the accidental shifting of just one such stem might make a difference of over 5% in the weight of any single sample. Anyone who has sampled alfalfa, with its bunching of stems above definitely and irregularly separated roots, knows the practical impossibility of obtaining uniform samples from an area as small as 1 square foot.

An important argument against the validity of these claims was advanced by a fellow agronomist who put it this way, "If there were any such advantage in weight as Curtis reports for cutting in the afternoon over cutting in the morning, practical farmers would have discovered it generations ago".—C. J. WILLARD, *Ohio Agricultural Experiment Station and the Ohio State University, Columbus, Ohio.*

YIELD AND CHEMICAL CONTENT OF ALFALFA CUT AT DIFFERENT TIMES OF THE DAY AND NIGHT

CURTIS[1] recently reported that cuttings of alfalfa made in the afternoon contained approximately 19% more dry matter per acre and had a carbohydrate content 83% higher than cuttings made either in the morning of the same day or the morning of the following day. During the first cutting of alfalfa at the Beltsville Research Center, a number of time-of-day cutting tests were made; and since these independent tests check so closely and are not in agreement with the results obtained by Curtis, it seems desirable to make the Beltsville results available to other interested workers.

The results here described are from two separate independent experiments—one by the Bureau of Dairy Industry and the other by the Bureau of Plant Industry, Soils, and Agricultural Engineering—on fields approximately 5 miles apart. All of the cuttings were made between May 30 and June 1, 1944.

The weather was partly cloudy on May 27, mostly clear on May 28, and clear with near maximum sunlight intensity (solar and sky radiations over 600 gm-cal per cm^2) on May 29, 30, and 31. Air temperatures ranged from 49° to 86° F on May 30 and from 50° to 92° on May 31, with a following minimum of 60° on June 1. Humidity was high at night, with a heavy dew each morning of May 30 and 31, but with very little dew on the morning of June 1. Minimum daytime humidities were 37% on May 30 and 36% on May 31. Relatively little wind occurred during May 30 and 31, the total air movement being 45.75 miles and 45.25 miles, respectively, in 24 hours.

In the experiment by the Division of Forage Crops and Diseases, plots of alfalfa in the regular varietal test were divided into three parts. One part was harvested between 8:30 and 9:30 a.m. May 31, one at 3:30 to 4:15 p.m. May 31, and one at 8:30 to 9:30 a.m. June 1, 1944. Seven varieties, Grimm, Ladak, Cossack, Hardigan, Hardistan, Buffalo, and Ranger, were included in the test, with three plots of each variety being utilized, making a total of 21 replications of the treatment. The original plots were 5 feet by 20 feet, running east and west, making the portions harvested for each treatment 5 feet by 6 feet 8 inches. The ends and center of the plots were randomized with respect to time of cutting, with restrictions so that there were an equal number (seven) of east ends, centers, and west ends in each time-of-cutting treatment. The subplots for each variety were also arranged in this manner. Cuttings were made by hand. There were good stands on all plots in this 2-year-old field. The stage of growth varied from 18% bloom for Buffalo to 42% bloom for Grimm. The crop had been making rapid growth.

The entire yield from each subplot was placed in a burlap bag and weighed immediately. The material was placed in a drier within about an hour after cutting and dried to a moisture-free basis. Weights were again taken and the weight of the bags subtracted from both green and dry weights. The percentage of moisture and the

[1]CURTIS, O. F. The food content of forage crops as influenced by the time of day at which they are cut. Jour. Amer. Soc. Agron., 36:401–416. 1944.

dry-weight yields per acre were calculated from these figures. Chemical analyses were to be run on the forage, but the dry-matter yields obtained by the Bureau of Dairy Industry corresponded so closely that it was considered unnecessary to duplicate the chemical work. The yields of dry matter from the different cutting treatments calculated on an acre basis are given in Table 1. Multiplying the dry-weight yields by 1.13 would give the approximate hay yields per acre.

TABLE 1.—*Dry-weight yield per acre and percentage of dry matter of alfalfa cut at three periods May 31 and June 1, 1944, Beltsville, Md.*

Period	Dry matter	
	Pounds per acre	%
May 31, 8:30–9:30 a.m.	3,684*	24.6*
May 31, 3:30–4:15 p.m.	3,605	26.6
June 1, 8:30–9:30 a.m.	3,703	25.2

*Difference required for statistical significance between any two average yields is 194 pounds per acre at the 5% point. 1.14% is required for a significant difference in dry-matter content.

The dry-matter yield from the mid-afternoon cutting was slightly lower than either of the morning cuttings, but this difference is not statistically significant. In fact, there is no significant difference between any of the cutting periods and, moreover, the analysis of variance indicates no differential response among the varieties regardless of stage of maturity or total yield. As expected, the dry matter content was about 2% higher in the afternoon than in the morning cuttings, but the increased green weight of the morning cuttings more than made up for this difference. The afternoon cutting was significantly higher in dry-matter content than the morning cuttings.

Investigations by the Bureau of Dairy Industry were conducted on an alfalfa field 3 years old. It was nearly free from weeds and had a uniformly good stand. The plants were about 30 inches tall and were from a quarter to a half in bloom. The field was divided into four areas to provide four replications.

Beginning at 7 a.m. (E.W.T.) on May 30 and continuing to 7 a.m. on May 31, 1944, strips of alfalfa 20 inches wide and 49 feet 2 inches long (82.1 square feet) were cut from each of four plots every other hour on the hour. The material from each strip (plot) was sacked, run through an ensilage cutter set for a ¼-inch cut, resacked, and weighed separately. The net chopped weights were taken as the yield. The total chopped material from all four plots at each cutting (328.4 square feet) was then mixed together thoroughly and sampled. Samples were taken in quart mason jars for moisture, nitrogen, and carotene determinations, and were put in a refrigerator immediately. Samples were taken in cloth bags and dried for regular chemical analyses.[2] Elapsed time following cutting averaged about 10 minutes for raking and sacking, 30 minutes for chopping and weighing, and 45 minutes for mixing and sampling. The results of the tests are given in Table 2.

[2]The analyses were made by C. G. Melin, Bureau of Dairy Industry.

TABLE 2.—*Green and dry weights per acre, percentage of moisture, and chemical analyses of the dry matter of alfalfa harvested at 2-hour intervals over a 24-hour period, May 30 and 31, 1944.*

Hour of day	Green weight, lbs.	Dry matter, lbs.	Moisture, %	Percentage composition of dry matter					
				Nitrogen	Crude protein*	N-free extract	Crude fiber	Ether extract	Ash
7 a.m.	14,359	3,593	75.0	2.55	15.91	39.57	35.42	1.90	7.20
9 a.m.	13,397	3,670	72.6	2.68	16.72	39.88	35.11	1.81	6.48
11 a.m.	12,376	3,580	71.1	2.60	16.22	40.09	35.75	1.82	6.12
1 p.m.	12,124	3,619	70.2	2.60	16.23	41.72	34.22	1.69	6.14
3 p.m.	12,376	3,733	69.9	2.47	15.42	39.84	36.94	1.71	6.09
5 p.m.	12,575	3,701	70.6	2.54	15.89	40.85	35.60	1.82	5.84
7 p.m.	12,455	3,571	71.4	2.50	15.64	40.16	36.44	1.77	5.99
9 p.m.	13,974	3,947	71.8	2.52	15.77	40.09	35.47	1.73	6.93
11 p.m.	14,631	4,012	72.6	2.54	15.86	38.62	36.32	1.86	7.34
1 a.m.	14,206	3,751	73.6	2.60	16.22	38.83	35.17	1.86	7.92
3 a.m.	15,192	3,903	74.4	2.66	16.62	37.20	36.00	1.84	8.67
5 a.m.	15,145	3,839	74.7	2.62	16.35	37.38	36.49	1.70	8.08
7 a.m.	14,518	3,700	74.6	2.49	15.55	39.07	35.89	1.83	7.66

*Nitrogen × 6.25.

Starting at 7 a.m., the total weight and percentage of moisture of the green alfalfa declined until early afternoon and then increased gradually until early morning. The dry-matter yields at 2-hour intervals from 7 a.m. to 7 p.m. and at 7 a.m. the next morning were not significantly different. Although some fluctuation in yields was expected because of the technic employed, it is evident that the yields of both green and dry matter averaged higher at night than during the day. A careful examination of the plots after they were clipped showed that the increased yield at night could be attributed to field variations instead of to diurnal variations.

There were no significant changes in the nitrogen, crude fiber, or ether-extract content of the dry matter at any time of the day or night. Nitrogen-free extract was slightly higher during the day than at night. The high point was reached at 1 p.m. and the low point at 3 a.m. Ash was lower during the daytime than at night, the lowest point being at 5 p.m. and the highest at 3 a.m.

The carotene content of the green alfalfa after chopping was found to be 149 micrograms per gram of dry matter at 7 a.m.; 147 at 9 a.m.; 132 at 11 a.m.; 130 at 1 p.m.; 127 at 3 p.m.; and 130 at 5 p.m. Because of unavoidable delays in completing carotene analyses on samples of later cuttings, the data were not reliable and therefore are not reported here.

Considering all data, there is no evidence of any increase in yield of dry matter, nitrogen, crude fiber, ether extract, or carotene in the alfalfa plant during the afternoon or evening over the night-time or morning periods of the day under the conditions of this test. However, there is evidence of a slightly higher nitrogen-free extract and a lower ash content in the dry matter during the daytime than at night, with no significant differences between late morning, afternoon,

and early evening periods of the day. While it may be possible, therefore, that some slight benefit may result from hay cut in the afternoon compared to early morning, this superiority does not appear to approach the 19% gain in dry matter reported by Curtis. Moreover, practical considerations of methods of hay making must be balanced against any advantages of late afternoon cutting before specific recommendations for time of cutting can be made.—T. E. WOODWARD AND J. B. SHEPHERD, *Bureau of Dairy Industry*, AND H. M. TYSDAL, *Bureau of Plant Industry, Soils, and Agricultural Engineering, Agricultural Research Administration, U. S. Dept. of Agriculture.*

AFTERNOON VS. MORNING CUTTING OF ALFALFA: COMMENTS ON NOTES BY WOODWARD, SHEPHERD, AND TYSDAL AND BY WILLARD

ACCORDING to the editorial policy of the JOURNAL, I have had the privilege of seeing two notes which oppose the conclusion presented in my paper[1], and I appreciate the opportunity to submit replies to these two papers.

It is true that the dry weight measurements reported by Woodward, Shepherd, and Tysdal[2] do not show any significant differences between morning and afternoon cuttings of alfalfa, and in this respect do not support my findings. But it is obvious from their data in both Tables 1 and 2 that their plots were too variable to show significant differences in total dry weight. The figures they present point to a loss in dry matter during the day and a gain at night, which, of course, is impossible except under the highly improbable situation in which transport and respiration during the day exceeded photosynthesis, and transport from the roots to the tops takes place at night. But the fact that their dry weight findings show no significant differences can hardly be claimed to refute my findings in which 7 out of 12 separate sets showed statistically significant gains during the day and only 2, with highly variable plots, showed a loss comparable to theirs, but this loss during the day, like theirs, was not statistically significant.

Although their dry weight measurements do not show significant differences between morning and afternoon, their data on percentage ash, percentage nitrogen, and percentage carotene, as well as those on nitrogen-free extract, clearly point to a gain in total dry matter and digestible material during the day and loss at night in amounts of the same magnitude that I observed and reported in my paper. Therefore I disagree with their two statements, ". . . . these independent tests. . . . are not in agreement with the results obtained by Curtis . . . .," and "Considering all data, there is no evidence of any increase in yield of dry matter. . . ."

[1]CURTIS, OTIS F. The food content of forage crops as influenced by the time of day at which they are cut. Jour. Amer. Soc. Agron., 36:401–416. 1944.

[2]WOODWARD, T. E., SHEPHERD, J. B., and TYSDAL, H. M. Yield and chemical content of alfalfa cut at different times of the day and night. Jour. Amer. Soc. Agron., 36: 940–943. 1944.

The data from Table 2 of their paper showing the changes in ash over a 24-hour period, when expressed as percentages of dry weight, are presented in the dotted line of Fig. 1. This is a rather smooth curve showing a diminution in percentage as the day advanced, reaching a minimum at 5 p.m., then rising to a maximum at 3 a.m., diminishing again at 5 a.m. and still more at 7 a.m. The smoothness of the curve clearly indicates that the differences in ash percentage are not due to variability of the material or inaccuracies in determination but to a true change in percentage as related to time of harvest. It is almost certain that the total ash per plant or per unit area of field does not diminish during the day and increase at night. It is probable that the total ash increases slightly over a 24-hour period. Most of this slight increase probably takes place during the day and possibly some also at night, although there is evidence for some slight net loss at night by leaching with dew. They report a heavy dew on the night of this experiment. Any real changes in total ash, therefore, will tend to minimize the following calculations rather than magnify them. It is thus entirely safe to assume that there was no real change in total ash per unit area of field during the 24-hour

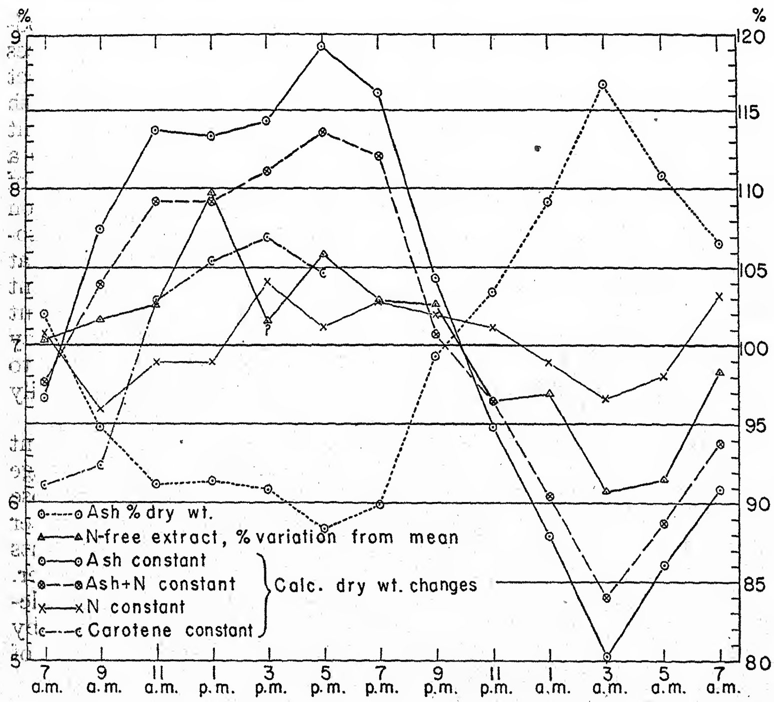


FIG. 1.—Composition changes over a 24-hour period based on data in Table 2 of Woodward, Shepherd, and Tysdal. Ash as percentage of dry weight is indicated by the dotted line referring to figures at the left. All the other curves show variations from the mean which is taken as 100%, and refer to the figures at the right.

period. Accepting such an assumption, the most likely if not the only explanation for the decrease in percentage of ash from early morning to late afternoon (unless there is some systematic error) is that the dry matter has increased as a result of photosynthesis. On the same assumption the steady increase in percentage ash from sunset of the first day to sunrise the next morning must have resulted from loss of dry matter by respiration and translocation.

Assuming that the total ash remains constant it is a simple matter to calculate the gain in dry matter necessary, for example, to change a sample containing 7.20% ash at 7 a.m. to 5.84% at 5 p.m. With total ash remaining constant the sample containing 7.2% in the morning must gain 23.3% in total dry matter to lower the percentage ash to 5.84%. Taking the average of all the percentage determinations of ash as 100 and assuming that the total ash has not changed, I have calculated the changes in dry matter from one sampling period to another that would be necessary to bring the percentage ash from the mean to that at each sampling period. These data are indicated by the solid line connecting open circles in Fig. 1. It is interesting that the extreme difference in total dry matter of 38.9% between the indicated maximum dry matter at 5 p.m. and the minimum at 3 a.m. is about double the figure of 19% that I presented in my paper. Although these extremes occur at the times that would be expected both from theoretical considerations and from evidence in several published papers, they appear greater than one would usually expect. Average figures based on the four afternoon determinations (1, 3, 5, 7 p.m., av. + 15.76%) and the five morning figures (7, 1, 3, 5, 7 a.m., av. − 11.65%) point to an average difference of 27.41% in total dry matter between early morning and afternoon.

The nitrogen determinations do not show changes as great or as regular as those for total ash. It is known that nitrogen is an element that migrates readily, and evidence from other sources indicates that nitrogen moves into leaves (and probably shoots) during the day and out of leaves and possibly out of leafy shoots during the night. This may largely account for the smaller calculated changes in dry matter when based on the less likely assumption that the total nitrogen remains constant during the 24-hour period. These calculations are indicated in the line connecting Xs of Fig. 1. Another factor that might partly account for the less variation in percentage nitrogen is that more of the nitrogen in the early morning samples is likely to be in the form of nitrate and less in the form of organic nitrogen, and therefore may be lost in making determinations of total nitrogen, especially if the method was not modified to recover nitrate nitrogen. In spite of these objections to using nitrogen as a reference element, the curve shows the same trend as that based on percentage ash. The extreme difference in dry matter between morning and afternoon, assuming nitrogen constant, is 8.16%.

Assuming that total ash plus total nitrogen remains constant, the curve is as indicated in the broken line of Fig. 1. The difference between extremes on this curve is 29.58% and that between the average of the five morning figures (7, 1, 3, 5, 7 a.m., av. −9.05) and the four afternoon figures (1, 3, 5, 7 p.m., av. +11.44) is 20.49%.

Because of its instability one would hesitate in assuming that the total carotene remains constant. It is interesting, however, that the trend in percentage carotene content is very similar to that of ash and nitrogen, and calculations based on the much less dependable assumption of its constancy show changes in dry matter of the same order of magnitude (15.8%) as those based on the other constituents. If a reading for carotene had been available for 3 a.m., the time of minimum dry matter as indicated by the other criteria, the maximum difference would probably have been greater.

The changes in dry matter indicated by the calculations based on the assumption of constancy of ash, or of ash plus nitrogen, point to extremes greater than seem probable and greater than the amounts indicated by my own data. Although much of this calculated change is undoubtedly real, it seems that part of it may result from some systematic error. The authors say, "A careful examination of the plots after they were clipped showed that the increased yield at night could be attributed to field variations instead of to diurnal variations". This would point to a systematic or plot-trend error that would not show up in the statistical treatment which points to standard error between plots small enough to pick up differences of the magnitude indicated by the calculations. If some such systematic trend was correlated with leafiness of the stand (an increase in the leaf-stem ratio for the early morning samples), this might account in part for the higher percentage of ash. But if there was a difference in leafiness, one would expect a greater difference in nitrogen than in ash, rather than a smaller difference. Then, too, if there was a greater leafiness of the morning samples, this would have an effect tending to minimize the difference in nitrogen-free extract referred to below, because the nitrogen-free extract, as well as ash, nitrogen, and carotene, is relatively higher in the leaves, yet their data show an increase in nitrogen-free extract to be associated with a decrease in percentage ash.

A paper by Fonder[3] presents data on changes during the course of a day in the calcium and magnesium contents of leaves and stems of alfalfa. These data as presented in his Fig. 1, like those of Woodward, Shepherd, and Tysdal, show a decrease in these elements during the day and an increase at night when expressed as percentage of dry matter. Assuming that the total actual calcium or magnesium is constant over the 20 hours of his experiment, which is a very logical assumption, changes in dry matter necessary to bring about the recorded changes in percentage of the mineral elements can be easily calculated. When plotted in curves, as in Fig. 1, these show exactly comparable trends. The maximum differences in dry matter between morning and afternoon are 19.7% as calculated from calcium in the leaves, 33.5% calculated from calcium in the stems, and 19.2% for the shoot based on a weighted average of calcium in the leaves and stems. The corresponding figures for magnesium are

[3]FONDER, JOHN F. A critical study of the influence of soil type on the calcium and magnesium content and other physiological characters of the alfalfa plant. Soil Sci., 27:205–232. 1929.

18.2%, 14.7%, and 13.9%. (The fact that the calculated dry matter content of stems reached a maximum later in the day than that in the leaves is responsible for the weighted average in each case being lower than either stems or leaves separately.)

Woodward, Shepherd, and Tysdal suggest that the only real change that their data indicate is a slight increase in nitrogen-free extract during the day, but they imply that this increase is of no great significance. Slight differences in percentage, however, may be very misleading and may mean significant and large differences in actual amounts of material. For example, a 100-gram sample of hay containing 85% water must lose 25% of its fresh weight, or 29.4% of its original water, to make a difference of only 5%, that is to lower its water content to 80% (assuming no change in total dry matter). In like manner, a 100-gram sample containing 80% water must gain 33.33 grams of water, or 33.33% of its fresh weight, to raise the water content to 85%. This would mean a gain of 41.66% over its original water content. Similarly, the slight differences in percentage nitrogen-free extract indicate important real differences. Taking the mean of all their nitrogen-free extract determinations as 100, a curve showing the percentage change from this mean during the course of 24 hours is presented in the line connecting triangles in Fig. 1. This curve shows a maximum difference between early morning and afternoon at 1 p.m. of 18.94% in nitrogen-free extract. (The low point at 3 p.m. is probably due to an error in determination of crude fiber. Their crude fiber figure for 3 p.m. was 36.94% which was out of line with the other figures and the highest in the entire set of 13 determinations, thus making the datum for nitrogen-free extract exceptionally low). An average of the four afternoon figures (1, 3, 5, 7 p.m., av. +5.00), including the low 3 p.m. figure, when compared with the average of the five early morning figures (7, 1, 3, 5, 7 a.m., av. −5.53) shows a difference of 10.53% in nitrogen-free extract in favor of the afternoon cutting.

Another way to compare the effect of time of day on nitrogen-free extract is to compare the mean of the 13 determinations (39.48%) with the maximum at 1 p.m. (41.72%) and the minimum at 3 a.m. (37.20%). The difference between these extremes is 4.52 which is 11.45% of the mean. The corresponding difference between the average of the four afternoon determinations and the five early morning determinations is 2.21 which is 5.6% of the mean. Some may not consider these differences of 5.6 to 11.45% great enough to be of much significance, but they are based on the assumption of *no change* in total dry matter, yet there is certainly a gain in total dry matter during the day on clear days. The calculated average difference in total dry matter between the same morning and afternoon collections is 27.41% as indicated above. If the dry matter was 27.41% greater and this dry matter contained 5.6% more nitrogen-free extract, the true gain in nitrogen-free extract in the afternoon cuttings was 34.55%. Using the more conservative figure of 10% gain in total dry matter that I suggested in my original paper, the gain of 5.6% in nitrogen-free extract would mean a real gain per acre of 16.20%, while the average maximum figure of 19% that my data indicated

would mean a real gain of 25.65% in nitrogen-free extract per unit area of field.

Woodward, Shepherd, and Tysdal are correct in reporting that their data on dry weight per unit area do not support my findings, but as they themselves state their plots were too variable to give significant data on total dry weights per unit area. It seems to me, however, that their analyses as logically interpreted above offer very strong evidence in support of the conclusions presented in my paper. Their data, as well as those of Fonder, also strongly support the suggestion, presented in my original paper, that changes in dry matter from morning to night or night to morning, or from cloudy to sunny days or the reverse, may introduce serious errors in interpreting changes in composition of vegetative parts of plants especially when expressed on a dry-weight basis.

COMMENTS ON THE NOTE BY C. J. WILLARD[4]

Although Doctor Willard has no new evidence to offer, he has raised questions concerning my findings which have undoubtedly occurred to others; therefore a discussion of these points seems justified. I can readily see how he thinks the gain of 19% in total dry matter, or 512 pounds per acre, as reported in my paper, is high. I felt it was high myself and frankly said so in my paper and also in a letter I wrote him last January. As I stated at that time I think a gain of nearer 10% or 15%, or around 200 pounds per acre, is more likely for afternoon cutting. My published paper presented the data that were actually obtained and they were not out of line with dry-matter gains in leaves and leafy shoots reported in the papers mentioned in my article. In the discussion I mentioned a 10% gain in total dry-matter, intending to imply that this is a more probable and more usual figure, but on rereading it appears that this point was not as strongly emphasized as perhaps it should have been.

He refers to a short mimeographed note that was sent to county agents in June 1943 and a similar one that was published in the *American Agriculturist.* These notes were hastily prepared and hurried out during the haying season to neutralize wide publicity advocating cutting early in the morning before the dew was off. The average gain of 25% reported in these preliminary notes seemed excessively high, but it was the only figure available at the time. Furthermore, it was in agreement with published data on gains in foliage leaves and distinctly less than what we have been finding in experiments with entire young corn plants which have repeatedly shown gains of 50% in total dry matter over a 12-hour period, and in some cases gains up to 90%.

Willard argues that an average net gain during the growing season of only 75 to 150 pounds per day appears to make impossibly high the gross gain of 512 pounds on single days that I reported. I contend, however, that to acccount for an average *net* gain of 150 or 100 or even 75 pounds per day over the entire growing period there would

[4]WILLARD, C. J. Afternoon vs. morning cutting of alfalfa. Jour. Amer. Soc. Agron., 36:937-939. 1944.

almost certainly be required a *gross* gain on some of the days much in excess of the 100 to 150 pounds average net gain, and possible even in excess of the high figure for gross gain of 512 pounds that I mentioned. Following are some reasons why occasional gross gains of 500 pounds or more per acre would be necessary to account for an average net gain of 100 to 150 pounds per day: (a) In the early stages when the leaf surface is small it would be impossible to have more than a very small fraction of the average daily gain for the entire period. Therefore, much larger gains must necessarily take place at some later stage. (b) Many of the days in the humid East where this alfalfa was grown (as well as that to which Willard refers) were rainy and cloudy, thus allowing for very little, if any, net gain over some of the 24-hour periods. In fact, over occasional 24-hour periods during very cloudy weather there is likely to be a net loss of dry matter. (c) Willard's own data, as well as those of Thomas and Hill mentioned by him, indicate that the net gain in the roots may exceed that in the tops, and since part of this probably moves to the roots at night the average daily gross gain must greatly exceed the average net gain. (d) There must be an appreciable loss from the tops at night by respiration, thus necessitating for this reason alone a gross gain during the day appreciably in excess of the net gain. (e) There is often a considerable shedding of leaves, especially where growth is rank and lodging takes place. In plantings examined this summer there was evidence that more than half the leaves that had developed on the shoots had fallen before full bloom. This, however, may have been abnormal and due to a heavy infestation of leaf spot. Such losses would materially lower the average daily net gain calculated from the final net weight of tops. Since much more than half of the leaves had fallen before the cutting stage and yet at this stage the leaves constituted about 50% of the final dry weight, more than a third of the daily net gain must have been lost by this means alone which I would consider greater than a "tiny fraction" of the gross gain.

The data from Thomas and Hill, cited by Willard, seem to me to support the likelihood of finding high gross gains under the conditions of my own experiments, which were in most cases carried out on sunny days following periods of cloudy weather. There is evidence from several sources that gross gains by photosynthesis are likely to be greater on clear days following periods of low light than equally clear days following many other clear days. The very fact that total yields of dry matter in regions subject to frequent clouds and rains, where light is clearly limiting much of the time, is not very different from that in regions of infrequent clouds is rather strong evidence that gross gains on these clear days must be far in excess of daily gross gains as observed under the conditions of the experiments of Thomas and Hill.

The italicizing of the word "*average*" in the last line of his fourth paragraph suggests that he has an erroneous idea concerning the use I am making of averages. In the investigations of Thomas and Hill the technic was such that readings for a single day or from a single chamber are highly accurate from the standpoint of possible individual variations and are subject only to systematic variations result-

ing chiefly from enclosure in chambers in which gas from the soil may complicate matters. In my experiments, the yields are subject to marked individual plot variations and the harvest from any single plot, or even nine plots, does not give as accurate and reproducible a figure. In my experiments in comparing total yields there were several cases in which occasional randomized plots showed losses during the day or gains over night which are explainable only on the basis of variability. In the method used by Thomas and Hill such variations are not likely to occur. Averages of large numbers examined by statistical methods furnish the only data that are significant by the methods I used. I definitely stated in my paper that some of the very high figures for total dry matter per unit area, presented in my Table 2, in no way indicate the true change in total dry matter per acre any more than the negative figures indicate a true change. But when large numbers of randomized plots are averaged and the data indicate significant differences when treated statistically, the averages really mean something within the range of error indicated. Furthermore, this average was based on figures obtained in every case but one on days that had few or no clouds. With the one exception a definite attempt was made to select days that would give maximum gains. Therefore, instead of comparing Thomas and Hill's *maximum* with my *average*, we are really comparing their maximum with my maximum, and they fall within less than 100 pounds of each other, 425 vs. 512. On recognizing that the maximum under their conditions would probably not equal the maximum on clear days in the East (as explained above), I feel that there is exceptionally good agreement.

A similar misinterpretation is indicated in his succeeding paragraphs also. He states that with an average gross gain of 512 pounds per acre and with a final net gain of tops of only 2,700 pounds there must be a loss from the tops of "326 pounds of material per acre per day". It did not occur to me that anyone would think an average maximum for clear days would be interpreted as an average daily gross gain for the entire growth period. It is not entirely clear what is meant in the material enclosed in parenthesis in this same paragraph. In my footnote I explained the failure of increase total yield per unit area as one progressed from the early cuttings to the late cuttings on the fact that different parts of the field were taken for the later cuttings and that the growth on that part of the field from which the first cuttings were taken was so heavy that there was severe lodging and much shedding of leaves. Therefore, for the later samples, plots were purposely laid out in a part of the field where the growth was distinctly less. I can see no grounds for expecting plots from an obviously light part of the field to yield more than plots of equal area but from a part where the growth was so heavy and coarse that there was severe lodging, even though the samples taken from the weaker stands were taken a few days later. Furthermore, there were not average gains of 500 pounds on "each day". These were the gross gains on clear days while several of the intervening days were very cloudy. A recognition of this fact would serve to answer other points mentioned in these same paragraphs.

Doctor Willard seems troubled about the small proportion of total gain in dry matter that is recoverable as starch or sugar and states, "Surely such materials are not translocated to the roots or respired?" There are many forms of easily digestible food that are not recoverable as starch or sugar. Alfalfa is rather notable for its rather low starch and sugar content and yet it produces a large yield of dry matter. It is probable that much of the photosynthate is tied up in hemicellulose, in proteins (conversion of ammonia, nitrates, and amino acids to protein), and possibly also in other forms.

Commenting on his last paragraph preceding the summary, there is some evidence that respiration of cut shoots will be less than that of those attached to the roots, but it is largely indirect evidence. I agree with him in part that cutting forage materials like alfalfa in the afternoon rather than the next morning is likely to reduce somewhat the carbohydrate that might otherwise move to the roots, but it is conceivable that plants so treated may recover with even less injury than those not cut until the following morning. There is so little direct evidence on this aspect that further discussion should await more experimental evidence. A point that is less speculative, however, and one that he has overlooked, is that waiting until afternoon to cut alfalfa rather than cutting it the first thing in the morning is very likely to increase rather than decrease the food supply to the roots. Not infrequently a farmer will delay cutting because of cloudy or rainy weather and then cut the first thing in the morning on the first clear day. At that time the food storage is at a minimum. If he waits until afternoon or evening to cut, there will be not only more food in the forage for the cattle but also more in the roots, because it is probable that much, if not most, of the food moves to the roots during the day. Under item 2 in the summary he says, "Cutting in the evening would prevent one day's translocation to the roots——". As a maximum, however, it would prevent translocation for only the one *night* and that only when compared with cutting the *next* morning. If compared with cutting the morning of the same day, there would be a real advantage to the roots in favor of afternoon cutting as they will then have received what has been transported to them during the day.

I would grant that for most alfalfa fields square-foot samples are too small for obtaining significant data. The particular field used in my experiment had several regions in it where the stand was exceptionally uniform and these were the regions in which the marking frames were placed. It would, of course, be hopeless to use square-foot areas in most alfalfa fields and especially in older fields where, although the tops may appear uniform, the stems stand in bunches. I would contend that the use of well-matched small areas or even individual plants, where the treatments are randomized and where there is no chance for systematic error, is likely to give better comparisons between treatments of the sort reported in my paper than areas of a square yard, a tenth of an acre, or even larger. The technic I have used of course would not be applicable to test effects of most other variables, such as fertilizer treatments, cultural treatments, variety differences, etc. Nor would such small plots be suitable

for estimating actual yields from large fields of an acre or more. That is, such small samples, even though expanded to express changes in total yield on an acre basis, are not to be considered as representative samples of the large field in which the frames are placed but merely indicate the increase to be expected per acre of field of which each block of 9 square feet is representative.

Dozens of cases could be cited in direct refutation of the argument presented in his last paragraph, that if there was anything in this effect of time of day practical farmers would have discovered it long ago. On pages 104 to 106 of the bulletin to which he refers (Ohio Agr. Exp. Sta. Bul. 540) and of which he is senior author, Doctor Willard cites three questionable practices recommended by "practical" farmers. I shall quote but two of them. "Fifteen years ago the standard recommendation for cutting alfalfa in humid regions was to cut it when the shoots of the next crop could be found at the crown of the plant. Moore and Graber of the Wisconsin Agricultural Experiment Station—were apparently the first to challenge with experimental data this almost universal recommendation". (Page 105). "Older articles and textbooks on alfalfa frequently make the statement that if these shoots at the crown become tall enough to cut with the mower the next cutting will be injured. This has never proved to be true in these experiments". Another questionable practice of "practical growers" is described at the bottom of page 106. Most of the favorable or unfavorable practices that are likely to be recognized by practical farmers are those that involve visible effects on growth or yield. The time of day at which forage crops are cut is likely to have no visible or easily recognizable effect on the material even though it may have a marked effect on its composition and food value.

It appears that Doctor Willard does not believe that a gain of 10% to 20% in total dry matter in a 10- to 12-hour period of daylight is possible, and his only explanation of my findings is that the plots were too small to offer reliable data. However, he makes no comment on my references to gains of the same magnitude that have been reported for the leaves of several kinds of herbaceous plants, as well as for leafy shoots in the only case in which data for shoots are reported. The changes in percentage ash or percentage of a single element, like calcium, that take place in alfalfa during a 24-hour period, as reported by Woodward, Shepherd, and Tysdal and by Fonder, clearly point to changes in total dry matter of the same magnitude that I have found. What is needed is more evidence from experiments with forage crops to determine more exactly the magnitude of these changes as related to weather, stage of development, and kind of crop.—OTIS F. CURTIS, *Department of Botany, Cornell University, Ithaca, N. Y.*

FURTHER COMMENT ON "WHAT IT TAKES TO TEACH THE PLANT SCIENCES"

Doctor Edward F. Potthoff courteously showed me the manuscript of his comments on "What It Takes to Teach the Plant Sciences"[1] before submitting it to the editor of this Journal.[2] It seemed to me then that his apt analogy well emphasized the probable validity of my suggestion that the two characteristics which were rated highest might actually be the most important in teaching the class of students reached, and that the rest might well be left to the usual readers of this Journal. I am still of that opinion, but on the invitation of the editor of *Chronica Botanica*, I have submitted a somewhat more detailed statement on this particular point. This will be published in the autumn 1944 number of *Chronica Botanica*.—Neil E. Stevens, *Department of Botany, University of Illinois, Urbana, Ill.*

[1]Stevens, Neil E. What it takes to teach the plant sciences. Jour. Amer. Soc. Agron., 36:316–323. 1944.

[2]Potthoff, Edward F. Comment on "What it takes to teach the plant sciences". Jour. Amer. Soc. Agron., 36:712–713. 1944.

EFFECT OF SEED TREATMENT ON CASTOR BEANS

Results obtained from limited tests indicate that seed treatment of castor beans is of value in increasing stands. Castor bean seed planted in the greenhouse gave a higher percentage germination and less post-emergence damping-off when treated with Arasan or New Improved Ceresan. Kentucky 38 seed produced in 1942 was used. The seed was treated immediately prior to planting by shaking seed and treatment material together in a glass jar. Excess treatment material was removed by screening. The seed was planted in a soil bench with the temperature of the house approximately 65° F during the tests. The soil was watered lightly after planting and no more water was applied until emergence began.

Results of the greenhouse test are shown in the first four columns of Table 1 and in Fig. 1. Both Arasan and Ceresan were effective in increasing the percentage of emergence over no treatment, but the increase produced by Ceresan was nearly double that produced by

Table 1.—*Germination records of castor beans (Kentucky 38) in greenhouse (April 1944) and in the field (May 1944).*

Treatment	Average emergence (100 seeds planted)				
	Greenhouse test (duplicate plots)				Field test (4 replications), total emergence
	Strong plants	Weak plants	Emerged but died	Total emergence	
No treatment	9.0	11.0	9.5	29.5	71.0
Arasan.......	24.0	15.5	25.0	64.5	73.5
Ceresan......	43.5	15.5	13.5	72.5	76.7

FIG. 1.—Castor bean seedlings growing in greenhouse bench. No treatment (check) on the left and Ceresan seed treatment on the right.

Arasan. Ceresan was more effective also in preventing post-emergence losses. Seed treatment produced a more rapid and uniform germination of the seed in addition to the other advantages mentioned.

The results were so encouraging that a test was prepared for field planting. The seed was treated in the same manner as for the greenhouse test and was planted in the field on May 17, 1944, under ideal seedbed and growing conditions. Germination percentages were higher than in the greenhouse tests, but differences between treatments and the controls were not nearly so great. The average germination percentages for the field test are shown in the last column of Table 1. While all plants came up rapidly there was a slight advantage in favor of the treatments. Only four plants in the entire test died shortly following emergence. Two of these were in one check plot and the other two were in plots treated with Arasan.

Results obtained in these preliminary tests indicate that there are conditions under which the treatment of castor bean seed with Arasan or Ceresan is beneficial; and, on the other hand, there are conditions under which it may be of little or no advantage.—R. O. WEIBEL, *Agronomy Department, University of Illinois, Urbana, Ill.*

WHAT IS THE SOIL SOLVENT?

THE question of how plants obtain their mineral constituents from the soil is still baffling plant physiologists and soil chemists. The problem resolves itself into three general phases, *viz.*, the dissolution of the mineral elements in the soil solvent, their entrance into the root cells, and their retention and accumulation in the plant tissues. This note concerns itself exclusively with the first phase.

The low solubility of the mineral soil constituents in water has caused plant scientists to look for some other solvent which would account for the fact that these elements do find their way into the plant tissues, as it is generally accepted that the only way they can enter the roots is in dissolved state. The only possible soil solvent established with certainty is carbon dioxide excreted by the roots of plants or produced in the soil by microbiological activity. While there is some controversy as to the efficacy of this solvent, the consensus of opinion is that the solvent power of carbon dioxide cannot in itself account for the availability of the soil constituents to plants.[1] Many theories have been offered in this connection but none of them has been accepted as adequate.[2]

It is surprising that while the phenomenon of nitrification in soils is so well known, it has been suggested only comparatively recently by Stephenson[3] that the strong nitric acid formed in the process of nitrification may be largely instrumental in making the cation elements available to the plants. Stephenson, however, expressing this view in the general discussion of the complicated relation of nitrification to plant nutrition and soil acidity, has not stressed the point that the nitric acid formed in the process of nitrification may be the elusive general solvent (including the anions, particularly the phosphorus anions) looked for by so many scientists of several generations. In this note the approach to the subject is simplified. An attempt is also being made to give an objective estimate of the approximate amount of nitric nitrogen formed under crop conditions and of the pH it would impart to the soil water available to the plants.

The absolute estimation of nitrification in soils is connected with many difficulties; but it seems to the writer that the most practical way of estimating nitrification under plant-growing conditions is the estimation of the nitrogen in the growing crop, since it is generally accepted that nearly all the nitrogen enters the most common land plants in the form of nitrates. While the nitrogen found in a well-established crop does not represent all the nitrified nitrogen in the given area, it represents most of the nitrates produced during the active growing season, as very little nitrate nitrogen is found in the drainage water from soils under crops and very little of it is found in the soil itself under a vigorously growing crop. Some competition for nitrates is offered the cultivated crop by weeds and microorganisms; but when one estimates the nitrogen in a crop from a certain area, he may be sure that at least this much nitric acid was formed

[1]Science, 56: 294–298, 1922; 57: 299–301. 1923.
[2]Plant Phys., 5: 443–489. 1930.
[3]Soil Sci., 41: 187–196. 1936.

in that area during the growing season. Similarly, the ash content of a crop plant indicates that at least this much of the plant's mineral constituents was dissolved by the soil solvent.

Wheat grain may serve as a good example of the relation of nitrogen to the solubility of the mineral plant constituents. The average ash content of wheat grain is, in round numbers, about 2% and the average nitrogen content is also about 2%. Without going into the stoichiometry of the individual ash constituents, it is at once apparent that there was enough nitric acid in the soil around the plants to dissolve all the mineral elements found in the grain, especially when the relatively low atomic weight of nitrogen is taken into consideration.

It is obviously also essential to estimate roughly the pH that the nitric acid equivalent of the nitrogen found in a crop would impart to the soil water. A wheat crop will be taken again as the basis for calculation. An average yield of wheat at 20 bushels per acre and at 60 pounds per bushel will yield at 2% of nitrogen 24 pounds of nitrogen. The weight of the straw, which is about 1½ times the weight of the grain, would be 1,800 pounds, and the weight of nitrogen in the straw, assuming an average of 0.5% as the nitrogen content, would be 9 pounds. This would make a total nitrogen content for the crop of 33 pounds.

There is some difficulty, however, in estimating the volume of water in which this 33 pounds of nitrogen would be dissolved in order to determine the active acidity (pH) it would impart to the soil water available for the use of the plants. The volume of total rainfall on a given area can be easily estimated, but only part of it enters the soil and stays there. The volume equivalent of the water-holding capacity of a soil can also be estimated, but there is not always found in the soil enough moisture to satisfy the full water-holding capacity. Furthermore, it is impossible to estimate how many times the water held in the soil is renewed during the growing season of the crop. It seems that the most logical way of estimating the pH that the nitric acid equivalent of 33 pounds of nitrogen would impart to the soil water is to base the estimate on the amount of water transpired through the crop during the growing season.

The weight of the entire crop of wheat taken for an example in this discussion is approximately 3,000 pounds. The water of transpiration ranges from 200 to 500 pounds to 1 pound of plant material in the humid regions with which we are largely concerned. This would make from 600,000 pounds to 1,500,00 pounds of water of transpiration for the entire crop of wheat. The nitric acid equivalent of 33 pounds of nitrogen would impart to 600,000 pounds of water a pH of about 2.4 and to 1,500,000 pounds of water a pH of about 2.8. The active acidity at either one of these two magnitudes is higher than that at which phosphates of calcium, magnesium, and aluminum dissolve, and is very close to that at which ferric phosphate dissolves. Furthermore, it is obvious that some individual charges of the transpiration water would carry higher concentrations of nitric acid than those corresponding to the acidity magnitudes mentioned above, since these are only general averages of active acidity for the water of transpiration during the season of growth.

These considerations seem to point strongly to the conclusion that the nitric acid formed in the soil in the process of nitrification is the solvent which may account for the availability of the soil constituents, both cations and anions, to the plants. This would be in line with the well-known fact that the total ash content of wheat grain increases with the increase in the protein content of the grain. Preliminary results obtained by the writer also indicate that the calcium and iron content of wheat increases with the increase in protein relatively more than does the total ash of the grain.—JEHIEL DAVIDSON, *Bureau of Agricultural and Industrial Chemistry, Agricultural Research Administration, U. S. Dept. of Agriculture, Kansas State College, Manhattan, Kan.*

THE RELATION OF ATMOSPHERIC HUMIDITY TO MOISTURE IN COTTONSEED

COTTONSEED rapidly attains moisture equilibrium with the surrounding atmosphere. In humid regions storage of seed presents a problem of economic importance to farmers, seedsmen, and others who have occasion to store cottonseed for planting or milling purposes. At ordinary air temperatures safe storage is dependent largely on the moisture content of the seed; hence, information on the relation between seed moisture and the relative humidity of the storage atmosphere is of importance in determining conditions for safe storage. Such information is provided in this study.

The cottonseed used was well-matured seed of the Stoneville variety that had been in storage for approximately 1 year. Initial moisture content was 8.7% and germination was 90%. The seed was thoroughly mixed and divided into two lots. One lot was retained as normal, live seed, while the other lot was killed by heating at 100° C for 30 minutes.

Duplicate 150-gram samples of each lot were placed in desiccators over sulfuric acid solutions of the concentrations necessary to maintain the desired humidities. The data of Wilson[1] were used in preparing the solutions. Preliminary experiments had shown that cottonseed would reach approximate equilibrium in moisture content with the surrounding atmosphere in 4 weeks or less. Since a change in the moisture content of the seed would result in a change in the concentration of the solution over which it was stored, the original acid solutions in the desiccators were replaced with fresh solutions after 4 weeks. The desiccators were held at a constant temperature of 25° ± 1° C. The seeds were tested for moisture content after 8 weeks and 12 weeks storage. All moisture percentages are reported on a wet-weight basis.[2]

Table 1 shows the moisture content of live and dead seed at each of the humidities used. Relative humidities in the storage atmos-

[1]WILSON, ROBERT E. Humidity control by means of sulfuric acid solutions, with critical compilation of vapor pressure data. Jour. Ind. and Eng. Chem., 13:326–331. 1921.

[2]SIMPSON, D. M. Factors affecting the longevity of cottonseed. Jour. Agr. Res., 64:407–419. 1942.

TABLE 1.—*Moisture content of cottonseed after storage in desiccators in atmospheres of different relative humidities.*

Relative humidity of storage atmosphere, %	Moisture content of cottonseed after designated storage period, %			
	Live seed		Dead seed	
	8 weeks	12 weeks	8 weeks	12 weeks
10	3.7	3.5	3.3	3.0
25	6.0	5.7	4.7	4.7
35	6.4	6.1	5.3	5.1
50	8.1	8.0	6.6	6.6
65	9.7	9.5	9.0	8.7
75	11.5	12.0	10.9	11.7
90	19.9	18.7	20.8	21.0

pheres ranged from 10% to 90% and resulted in moisture contents in the seed ranging from 3.0% to 21.0%. The data indicate that non-viable seed is less hygroscopic than live seed. At the higher humidities deterioration was very rapid and viability was not maintained. At 90% relative humidity, both "live" and dead seed were in process of decomposition after 8 weeks storage. With the rotting of the material, moisture content could be expected to vary with the stage of decomposition and the rate of air movement through the sample.

The curve in Fig. 1 was plotted from the determinations of moisture of live cottonseed at seven conditions of relative humidity. The relation between seed moisture and relative humidity approximates a straight line for that portion of the curve below 65% saturation. At humidities above 65% the rate of increase in moisture in the seed was greatly accelerated with each increase in relative humidity, resulting in a rapid upturn in that portion of the curve. The values

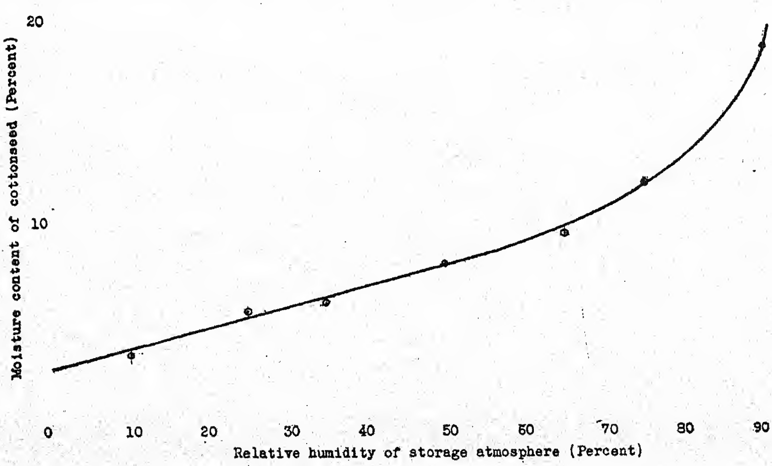


FIG. 1.—Relation of moisture content of cottonseed to relative humidity of the storage atmosphere.

derived from this curve are regarded as sufficiently accurate for estimation of either moisture content of cottonseed or the mean relative humidity of the storage atmosphere when the associated value is known. Although these values are based on data obtained under controlled experimental conditions, obviously minor variations from them may be expected with other lots of cottonseed or other methods of determination.

Previous experiments[3] have shown that cotton seed containing less than 10% moisture can be stored at ordinary air temperatures without danger of rapid deterioration. If the temperature is low (near 32° F), the seed is tolerant of higher moisture. Both temperature and moisture cannot be high, however, if rapid deterioration is to be prevented. Both temperature and moisture may vary greatly in different parts of a seed pile if free air circulation is not maintained. Since the seed is conditioned by the atmosphere in immediate contact with it, change in moisture content can occur only by change in atmospheric humidity through air circulation or diffusion. Storage of seed in large piles or tight bins would retard change in moisture content.

From Fig. 1 it may be observed that in an atmosphere having a relative humidity of over 70%, seed moisture would likely exceed 10% and unsafe storage would result if such conditions were long maintained. In seed storage houses with controlled ventilation, practical advantage may be taken of the fluctuating humidity of the outside atmosphere by allowing free circulation of air when the outside atmosphere is drier than that surrounding the seed and closing ventilators to prevent circulation when the conditions are reversed.—D. M. SIMPSON AND P. R. MILLER, *Division of Cotton and Other Fiber Crops and Diseases, Bureau of Plant Industry, Soils, and Agricultural Engineering, Agricultural Research Administration, U. S. Dept. of Agriculture, and the Tennessee Agricultural Experiment Station, Knoxville, Tenn., cooperating.*

[3]See footnote 2.

BOOK REVIEWS

SOURCE BOOK OF AGRICULTURAL CHEMISTRY

By Charles A. Browne. Waltham, Mass.: The Chronica Botanica Co.; New York: G. E. Stechert and Co. X 290 pages, illus. 1944. $5.

PERHAPS too often we marvel at the accomplishments of modern science without realizing how much our present knowledge is the result of the genius and labor of a selected few who lived a long time ago. A better acquaintance with the past of any science is sure to give a broader view of the present as well as of the possibilities of the future. But it is difficult to take time out in our busy life to read books on the history of science, unless they are of the quality of Doctor Browne's "Source Book of Agricultural Chemistry".

Both the chemist and the agronomist will read with interest this splendid volume which deals with the contributions to agricultural chemistry (in a broader sense) of some 60 philosophers, alchemists,

and chemists from ancient times to the beginning of the modern period in the mid-nineteenth century. The well-selected quotations (in English) of pertinent passages from the writings of these authors are accompanied by discussion and evaluation of the influence they exercised on subsequent developments. In fact, the volume gives the history of the genesis and evolution of our dominant ideas relating to agricultural chemistry.

One of the most interesting features of the text is the considerable space devoted to the descriptions of laboratory methods and equipment used by the early alchemists and chemists throughout the 2,000 years leading up to and including the period of Liebig. The volume contains many illustrations, including facsimilae, and is well organized and printed. One cannot help but feel that only an author of Doctor Browne's caliber and long sustained interest in the history of chemistry could have made a topic so pregnant with boredom into such an interesting and entertaining volume. While it is understood that it is a part of Volume 8 of *Chronica Botanica*, it is still regrettable that a book of such importance and lasting value has been released with paper cover.—Z. I. KERTESZ.

THE SOILS OF EQUATORIAL REGIONS, WITH SPECIAL REFERENCE TO THE NETHERLANDS EAST INDIES

By E. C. Jul. Mohr. Ann Arbor, Mich.: J. W. Edwards. Trans. from the Nederlandsch by Robert L. Pendleton. Edited by Robert F. Chandler. XII+766 pages, illus. Lithoprinted. 1944.

LESS organized information and fewer commonly accepted principles concerning the nature and genesis of Laterite soils have been developed than for those of any other great soil group. The same may be said for soil classification and geography in tropical areas generally. Relative to the great area and complexity of the soils, very few soil scientists have studied soils in the tropics; and many of these have been so specialized in their approach—geological, chemical, or agronomic—that their observations are often incomplete and difficult to compare or correlate.

The tropics offer great opportunities to the young scientist for service. The principles of general soil science apply, of course, but they need more precise development and local adaptation. Although the people living on the tropical soils have learned, through experience, how to handle them, truly enormous opportunities exist for increasing efficiency of production through higher yields, improved quality, and diversification of crops, and by more economical tillage and control of water.

Certainly the agricultural potentialities of many tropical lands have hardly been conceived. Yet there are no large areas awaiting only the plow. Careful fertilization, use and control of water, tillage, and planning of crop rotations are necessary. Further, soil diversity within a district or community is even greater than among soils of temperate regions. This fact gives special emphasis to soil classification and geography, based upon careful research, as a critical need for agricultural progress in the tropics.

The publication of Mohr's book in English is, therefore, an event of first importance, and Pendleton has rendered a great service by translating it. Mohr has studied the soils and agriculture of the Netherlands East Indies for many years from a broad point of view. His book shows skill and understanding in dynamic geology, chemistry, biology, and land management, as well as in soil science.

The first 190 pages deal with the general principles of weathering and soil development, in relation to parent rock, climate, vegetation, slope, and age. The remaining 500 pages of text deal specifically with the geology, climate, "ways in which weathering occurs and resulting soil types", and "evaluation and utilization of the soils" for individual areas (small islands and broad physiographic divisions of large islands) within the region. A wealth of data and observations has been poured into these pages, together with the author's theories and speculations in an unusual, but not unpleasant, personal style. But Mohr is careful to give the reader a sense of the relative reliability of both data and speculations.

Great emphasis is given by Mohr, and rightly, to parent rock. He stresses also the relation between local soil productivity and the age and nature of the volcanic materials. But he confuses a little the influence of parent rock in causing large differences among soils within the region, on the one hand, and in causing the fundamental properties of the soils, on the other. By reflection upon the contrasts between the soils of the Netherlands East Indies as a whole and those of temperate regions, which the author stresses, one sees the larger rôle of climate, and especially of living things, in their development.

Mohr stresses the activity of vegetation and microorganisms in soil development and relates their activities to the simultaneous geomorphological evolution of the landscape. The importance of the intermingling of weathering processes and soil-forming processes in the development of soil and landscape together is something more soil scientists need to appreciate. For example, the whole matter of soil rejuvenation through volcanic activity and normal erosion, including that induced by earthquakes, is very important in the tropics, because, generally, the young soils are the most productive.

The author included much interesting material on the causes and control of accelerated erosion in tropical regions where the problems are important but quite different than in the United States. He presents interesting theories on the nature, movement, and influence of soil water; on the natural occurrence of nitrogen in rocks and irrigation water; on the differentiation of soil horizons as related to the local soil environment; on the weathering of minerals; on the nature and rôle of organic matter; and on the segregation of minerals during the deposition and weathering of soil material. These problems, and many others of vital importance, are discussed from points of view not common to American classrooms.

Mohr does not present an organized scheme of soil classification; rather he lays a foundation for such a scheme. Attempts at detailed mapping of soil types, carefully defined in terms of their characteristics as he emphasizes them, would have helped the reader a great deal to grasp their geographic relationships and, indirectly, would

likely have helped the author to sharpen his own concepts of the main types and their significant variations. Although the geography of soils is discussed a great deal and some geological maps and climatic maps are presented as well as a good outline map of the region, it is unfortunate that soil maps are not included.

Perhaps because of some partial isolation, Mohr has developed many individual methods of symbolization and nomenclature for certain soil features and processes. In this book, however, he makes more use of work done in Russia and the United States than in his former one. Although the American student may be somewhat irritated by his special nomenclature, especially where the commonly accepted international terms could have been used as conveniently, he will have no real difficulty with it.

Even though this reviewer may not fully understand all of Mohr's theories, nor agree with some of his generalizations, he regards this book as "must" reading for all general soil scientists and more particularly for those concerned with any aspect of soils in tropical regions.—CHARLES E. KELLOGG.

A LIFE OF TRAVELS

By C. S. Rafinesque. Waltham, Mass.: Chronica Botanica Co. 80 pages, 3 portraits. 1944. $2.50.

THIS is a verbatim reprint edition of Rafinesque's autobiography published in Philadelphia in 1836. There is little in the booklet of direct professional interest to agronomists, but anyone interested in travel and the early development of descriptive biology in the United States may find the booklet worth reading. It is a simple narrative of a life of travel giving places visited and persons met, together with brief references to collections of biological material, particularly plants, and to the miscellaneous ventures of the author including some of his numerous publications.—R. J. GARBER.

AGRONOMIC AFFAIRS

NEW GRAIN INSPECTION REPORTS

THE trends in crop improvement or in crop deterioration have been indicated by the grain inspection records maintained by the U. S. Dept. of Agriculture. Beginning with the 1943 crop, much more comprehensive records will be available in that the inspection records for every inspection point in the United States will be compiled on mechanical tabulators. Many members of the Society and others who are interested in the inspection data at particular markets have already indicated the particular information which they desire. Because of the large number of reports, it will be impossible to publish data for every inspection point. Requests for information at any particular markets can be addressed to W. B. Combs, Extension Service, 1108 Post Office Building, Chicago 7, Ill. Mr. Combs

carries on a cooperative project with the Grain Products Branch, Office of Distribution, where the grain grading statistics are compiled.

ESSAY CONTEST

THROUGH the kindness of Doctor M. A. McCall, Bureau of Plant Industry, Soils and Agricultural Engineering, U. S. Dept. of Agriculture, and the *Northwestern Miller*, a fund of $100 has been given to the American Society of Agronomy to sponsor an undergraduate essay contest.

Due to limited college enrollments, it is planned to withhold the essay competition until such time that enough students may be available to warrant the award. It has been suggested that the essay should treat of some phase of wheat quality. The announcement of details and plans will be made at a later date by the Committee on Student Sections.

NEWS ITEMS

ACCORDING TO *Science*, Professor E. W. Lindstrom, Chairman of the Department of Genetics, Iowa State College, left on September 6 for Medellin, Colombia, where he will serve as exchange professor at the Facultad Nacional de Agronomia. The appointment was made under the auspices of the Division of Cultural Relationship of the Department of State in cooperation with the American Republics.

—A—

A SOIL SCIENCE SOCIETY of Oregon was organized at Oregon State College, Corvallis, Ore., September 6, 1944. Officers were chosen as follows: *President*, Dr. W. L. Powers, Oregon State College; *Vice President*, Dr. S. W. Cosby, Soil Conservation Service; *Secretary-Treasurer*, Dr. R. A. Pendleton, Bureau of Plant Industry, Soils, and Agricultural Engineering. Dr. R. M. Salter, Chief of the Bureau of Plant Industry, Soils, and Agricultural Engineering, was the principal speaker at the organization meeting.

—A—

WALKER L. VANDERVEST has been appointed Assistant Professor in Agronomy at the University of Wisconsin.

—A—

LT. HORACE S. SMITH, U. S. M. C., formerly Assistant in Agronomy and in charge of the wheat improvement program for the Oklahoma Agricultural Experiment Station, was killed in action on Guam on July 21.

—A—

DOCTOR GILBERT H. AHLGREN has been named head of the Department of Farm Crops at the New Jersey State College of Agriculture and the New Jersey Agricultural Experiment Station, New Brunswick, N. J.

According to *Science*, the British Minister of Agriculture has appointed Professor J. A. Scott-Watson, formerly Agricultural Attachè at the British Embassy in Washington, to be chief education and advisory officer to the Ministry under the provision of a recent act of Parliament establishing a National Advisory Service. Professor Scott-Watson has expressed himself as being deeply impressed by the development of agricultural research in the United States and is quoted as saying that the United States "now leads the world in this respect." He advocates that research workers of Great Britain be sent here for advanced training and that past contacts be strengthened in order to bring the full power of science to bear on farm problems.

—A—

The death of Doctor John R. Fain, Professor Emeritus of Agronomy, University of Georgia, occurred on March 26, 1944. Doctor Fain, long a member of the American Society of Agronomy, taught at the University of Tennessee, Virginia Polytechnic Institute, and was head of the Department of Agronomy of the College of Agriculture, University of Georgia, from 1907 to 1938, when he retired.

—A—

Doctor H. H. Zimmerley, Director of the Virginia Truck Experiment Station, Norfolk, Va., died early in October.

—A—

Doctor Ide P. Trotter of the Department of Agronomy, Texas Agricultural Experiment Station, has been appointed Director of the Texas Agricultural Extension Service, effective November 1st.

—A—

Doctor James A. Bizzell, Professor Emeritus of Agronomy at Cornell University, died at his home in Ithaca on November 1, at the age of 68.

—A—

Doctor Selman A. Waksman, microbiologist at the New Jersey Agricultural Experiment Station, gave the second Harvey Society Lecture of the current series at the New York Academy of Medicine on November 16. His topic was "The Production and Nature of Antibiotic Substances".

—A—

Doctor Harry V. Harlan, agronomist of the U. S. Dept. of Agriculture, died in Phoenix, Ariz., on November 6th at the age of 62. Dr. Harlan served the Department in many parts of the world as an agricultural explorer with special reference to the collecting of barley varieties. Since 1910 he had been in charge of the barley investigations for the Department and at the time of his death was attached to the field station at Sacaton, Ariz.

JOURNAL

OF THE

American Society of Agronomy

VOL. 36 DECEMBER, 1944 No. 12

SOIL AGGREGATION AS A FACTOR IN YIELDS FOLLOWING ALFALFA[1]

HAROLD E. MYERS AND HUGH G. MYERS[2]

THE favorable effect of alfalfa and legumes in general on the growth of subsequent crops has long been recognized. The beneficial influence of the legume is most frequently assigned to its influence in increasing the supply of available nitrogen, although it is recognized that other factors are involved. The influence of legumes when grown for a brief period is usually found to be of short duration.

Lyon (2)[3] showed that the favorable effects of both alfalfa and red clover were largely dissipated after 3 years of nonlegume cropping in New York. Likewise, the favorable effects of alfalfa on the yield of cotton were shown by Mirimanian (6) to decline rapidly after the third cotton crop.

Under Kansas conditions, Metzger (3, 4) showed that the favorable effects of alfalfa on the yield of succeeding crops of wheat usually has not extended beyond 3 years. However, he made soil studies which showed that for 7 to 10 years those soils which had previously grown alfalfa had an appreciably higher nitrate nitrogen content at wheat seeding time than occurred in similar soils that had not grown alfalfa. Analyses of the wheat grain showed that the alfalfa had increased the protein content for a period of at least 11 years after the alfalfa was plowed under, thus indicating that additional nitrogen was taken into the plant without increasing the yield. While in general the yield had not been favorably affected for more than 3 years, Metzger also found that in one season (1930) all plots which had previously grown alfalfa gave increased wheat yields regardless of the length of time the alfalfa had been grown and the length of the period up to 7 years since the alfalfa crop had been plowed down. This was an especially favorable season for wheat production.

Why the effect of the alfalfa on the yield of wheat has not persisted for the duration of the period that the supply of nitrate nitrogen was increased is a question that has remained unanswered. The study of Mirimanian (6) suggested that the decline in the effect of alfalfa

[1]Contribution No. 361, Department of Agronomy, Kansas Agricultural Experiment Station, Manhattan, Kans. Received for publication July 27, 1944.

[2]Agronomist, on leave, and Associate Agronomist, respectively.

[3]Figures in parenthesis refer to "Literature Cited," p. 969.

was the result of both chemical and physical changes within the soil. The fact that the increased wheat yields were noted for a much longer period after the breaking of the alfalfa when climatic conditions were favorable suggested that plant nutrients were not the limiting factor in the experiments reported by Metzger but that possibly some factor related to moisture and aeration relationships in the soil was involved. One factor that would influence these relationships and which is itself influenced by the legume is the structural make-up of the soil.

Sears, *et al.* (7) showed that sweet clover influenced favorably the yield of the first crop of corn even though all the top growth and as much of the root material as possible was removed from the soil. Since sweet clover has been shown to improve soil aggregation (Table 1), it would appear that this condition might have been a factor in influencing the results obtained by Sears.

Metzger and Hide studied the aggregation of the soil from legume, row crop, and oat plots which involved the same rotations as the study reported herein. Their results suggested that aggregation of soil from the row crop and oat plots was not greatly different from that of soil from the legume plots, but the latter did exhibit a tendency to become more dispersed with elapse of time since the legume crop. The average percentages of the total soil samples having a settling velocity in water equal to or less than 1.608 cm per second were 41.73, 42.74 and 44.11, respectively, for legumes, row crops, and oats. Mirimanian (6) showed a distinct positive relationship between noncapillary porosity of the soils and yield of cotton at various periods following alfalfa.

Ackerman and Myers (1) showed that while alfalfa had a marked effect on soil aggregation, this disappeared within 3 years after the alfalfa soil was broken.

The study herewith reported was made to obtain information on possible relationships between physical condition of the soil as measured by water-stable aggregates, and the failure of alfalfa and sweet clover to increase the yield of crops beyond the third season following the legume.

EXPERIMENTAL PROCEDURE

A group of rotation plots on the Agronomy Farm of the Kansas Agricultural Experiment Station was selected for this study. Rotations utilized were corn, oats, wheat; sorghum, oats, wheat; sweet clover, sweet clover, corn, oats, wheat; sweet clover, sweet clover, sorghum, oats, wheat; alfalfa, alfalfa, corn, oats, wheat; and alfalfa, alfalfa, sorghum, oats, wheat.

Since the favorable effect of the legumes on yield was shown usually to persist for only 3 years, the plots which had grown wheat in all rotations were sampled immediately after harvest in 1942 and before the soil was disturbed by tillage.

In April 1943 a second group of samples was taken from plots that were to be planted to row crops. Two additional sets of samples were taken in April 1944 from plots that had been seeded to wheat the previous fall and on plots that were to be planted to oats.

All samples were taken with a spade to a depth of 7 inches when the soil was in good moisture condition for plowing. The samples were spaced at approximately uniform intervals over the length of the 1/20-acre plots (161⅓ feet). Soon after sampling the samples were put through a ½-inch screen and allowed to air dry before analysis. The 1942 and 1943 samples were stored for approxi-

mately 6 months before being analyzed. The 1944 sets were analyzed within a month after sampling.

Aggregate analyses in duplicate were made by the method previously described (1). Although extra determinations were made when the first two duplicate determinations did not agree closely, only the first two were used in the statistical treatment of the results. The between-field-sample variations were significantly higher than the variations between replicate determinations even though as many as 20 field samples were taken from each 1/10-acre plot.

EXPERIMENTAL RESULTS AND DISCUSSION

The alfalfa and sweet clover crops increased the yield of oats 7.6 and 5.8 bushels, respectively, over a 13-year period, while wheat yields were increased 0.4 and 1.8 bushels, respectively, over a 12-year period. The corn and sorghum yields were influenced to such a marked extent by summer drouths that it is believed the yields of these crops do not reflect the possible favorable effects of the legumes, and, therefore, are not given.

Since the results showed that the samples obtained from the corn and sorghum rotations were not significantly different, the two sets of results were grouped and the two crops will hereafter be referred to as row crops.

The data with their statistical significance are given in Table 1. The changes in percentage of aggregates larger than 0.105 mm are shown graphically in Fig. 1.

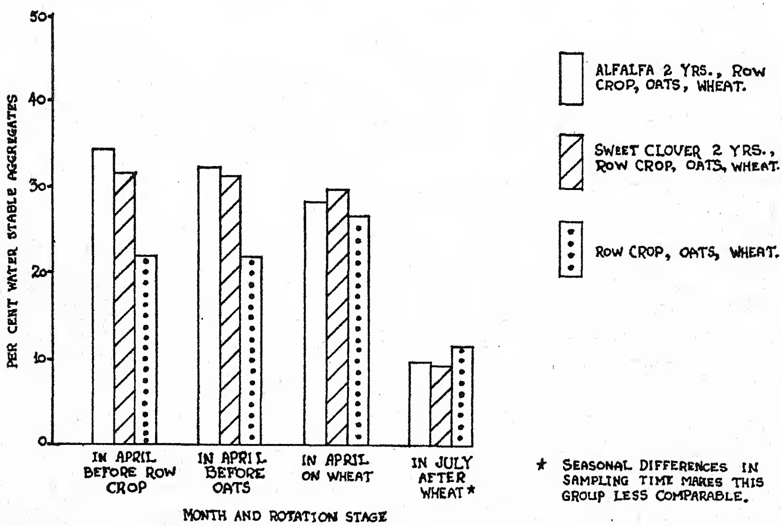


FIG 1.—Mean percentage water-stable aggregates larger than 0.105 mm at different stages in three rotations.

It is thought that the percentage of water-stable aggregates may have been high in all samples taken on wheat plots in April because of temporary favorable effects of the crop upon aggregation. The wheat roots were well distributed through the surface soil at the time

of sampling. This set of samples was taken on the same afternoon as were the samples from the plots that were to be seeded to oats.

TABLE 1.—*Mean percentage of water-stable aggregates at successive intervals in legume rotation and at corresponding times in a rotation without legumes.*

Rotation stage	Months after legume in legume rotation	Rotation			Significance level of F	
		Row crop, oats, wheat, alfalfa 2 years	Row crop, oats, wheat, sweet clover 2 years	Row crop, oats, wheat	Between treatments	Legume rotations vs. nonlegume rotations
Aggregates Larger Than 0.105 mm						
In April before row crops	6	34.2	31.7	21.6	<.01	<<.001
In April before oats......	18	32.4	30.8	20.5	<.001	<<.001
In April on winter wheat	30	28.4	29.4	26.8	N.S.	—
In July after winter wheat	33	9.9	9.3	11.8	N.S.	—
Aggregates Larger Than 2 mm						
In April before row crops	6	3.3	2.9	1.4	<.01	<.001
In April before oats......	18	5.4	4.5	1.4	<.001	<.001
In April on winter wheat	30	2.5	3.0	1.6	.05+	<.05
In July after winter wheat	33	0.65	0.92	0.94	N.S.	—
Aggregates Larger Than 4 mm						
In April before row crops	6	0.88	0.78	0.38	N.S.	—
In April before oats......	18	1.72	1.16	0.29	<.001	<.001
In April on winter wheat	30	0.66	0.53	0.21	N.S.	—
In July after winter wheat	33	0.12	0.15	0.20	N.S.	—

By evaluating the results obtained in the light of yield response from alfalfa on succeeding wheat crops, as reported by Metzger (3, 4), and in the light of results reported by others, it appears evident that there was some relationship between soil aggregation and the length of the favorable effects of alfalfa on yields of subsequent crops. Since the alfalfa influenced the yields for a much longer period in seasons with a favorable rainfall, it suggested that the physical condition of the soil was related to yield largely through its influence on water relationships.

Under Kansas conditions the response of wheat from nitrogenous fertilizers has not been satisfactory. This has been true irrespective of the fact that many soils have declined seriously in total nitrogen. This study offers a possible explanation for the frequent failure of commercial nitrogen to produce good results, since an increased nitrate nitrogen supply resulting from the growth of alfalfa has not increased the yield consistently after the favorable effects on soil structure have disappeared.

SUMMARY

Aggregate analyses were made of soil samples taken at successive intervals after plowing down of alfalfa and sweet clover in rotations of legume 2 years, row crop, oats, wheat and at corresponding times in a rotation of row crop, oats, wheat. Approximately 50% higher total aggregation was found in samples taken before row crop and before oats from the legume rotations than those taken from the nonlegume rotations. Differences in aggregation were not significant in samples removed from the wheat plots either in early spring or after harvest. This apparent break down of water-stable aggregates in the legume rotations coincides with small grain yields in these rotations. The legume rotations have increased oat yields an average of 6.7 bushels over the nonlegume rotation yields, but have increased wheat yields only 1.1 bushels.

It appears that the favorable effects of the legume upon subsequent small grain yields under these conditions may be largely through its effect on soil structure rather than from its influence on soil nitrogen.

LITERATURE CITED

1. Ackerman, F. G., and Myers, H. E. Study of some factors influencing aggregation of a claypan soil. Soil Sci., 55:405–413. 1943.
2. Lyon, T. L. Legumes as a source of available nitrogen in crop rotations. Cornell Univ. Agr. Exp. Sta. Bul. 500. 1930.
3. Metzger, W. H. The residual effect of alfalfa cropping periods of various lengths upon the yield and protein content of succeeding wheat crops. Jour. Amer. Soc. Agron., 27:653–659. 1935.
4. ————. Nitrogen and organic carbon of soils as influenced by cropping systems and soil treatments. Kans. Agr. Exp. Sta. Tech. Bul. 45. 1939.
5. ———— and Hide, J. C. Effect of certain crops and soil treatments on soil aggregation and the distribution of organic carbon in relation to aggregate size. Jour. Amer. Soc. Agron., 30:833–843. 1938.
6. Mirimanian, Kh. P. The duration of the favorable influence of alfalfa on the cotton fields of Armenia. Jour. Amer. Soc. Agron., 26:475–480. 1934.
7. Sears, O. H., Pieper, J. J., Burlison, W. L. Sweet clover in Illinois. Ill. Agr. Exp. Sta. Bul. 394. 1933.

THE EFFECT OF NITROGEN UPON THE RESPONSE OF COTTON AND OATS TO PHOSPHORUS[1]

Russell Coleman[2]

MUCH of the large amount of phosphate fertilizer used in Mississippi fails to give increased crop yields. Numerous attempts have been made to explain why the soils low in phosphate do not respond to applied phosphorus. The most widely accepted explanation is that these soils fix the phosphate applied as fertilizer in an unavailable form. This may be true in some cases, but there is evidence which indicates that this is not always the controlling factor. Since a low nitrogen content of Mississippi soils is often the limiting factor in crop production, and since there appears to be a relationship between the utilization of nitrogen and phosphorus by the plant, it seems possible that the nitrogen content of the soil is often too low to permit the proper utilization of applied phosphorus. The purpose of the present investigation was to study the effect of the nitrogen level of the soil upon the response of cotton and oats to phosphorus.

LITERATURE REVIEW

Certain investigators have found a relationship between the utilization of nitrogen and phosphorus by the plant. Dutoit and Beater (3)[3] grew plants at three levels of N-P-K, and found that more phosphorus was absorbed at the higher levels of nitrogen. Sircar and Sen (5), growing rice at three different levels of phosphorus, found that the greatest intake of nitrogen was associated with the highest phosphorus level. Breazeale (2), investigating the influence of various elements upon their absorption, concluded that the absorption of nitrogen is not influenced by the presence of any other element, but that the absorption of phosphate is stimulated by the presence of nitrogen. On the other hand, Beckenback, *et al.* (1) reported that the nitrogen content of corn leaves is not affected by the phosphorus content of the substrate, and that the phosphorus content of corn tissue is influenced only by the concentration of phosphorus itself.

One of the principal functions of phosphorus, according to Kraybill (4), is in the reduction of nitrogen compounds within the plant. If phosphorus is limiting, nitrates will not be properly reduced, and if nitrogen is deficient, then phosphorus may accumulate without being properly utilized by the plant. Most of the previous studies show that the utilization of nitrogen and phosphorus by the plant is interrelated, and they suggest that a deficiency of either element may affect the proper utilization of the other by plants.

EXPERIMENTAL PROCEDURE

Experiments in which varying amounts of phosphorus were applied to soils having different levels of nitrogen were conducted in the greenhouse and in the field.

In the greenhouse, oats were grown in pots containing 25 pounds of Paden silt loam. The fertilizers used in the treatment shown in Table 1 were prepared by mixing the appropriate amounts of nitrogen as sodium nitrate, phosphorus as monocalcium phosphate, and potash as muriate of potash. They were applied in solution after the oats had germinated. Fifty plants per pot were grown for

[1]Contribution from the Department of Agronomy (Soils Division), Mississippi Agricultural Experiment Station, State College, Miss. Published with approval of the Director, Paper No. 79, New Series. Received for publication August 18, 1944.

[2]Associate in Soils.

[3]Figures in parenthesis refer to "Literature Cited", p. 975.

60 days, after which the oats were harvested, dried, weighed, and analyzed for phosphorus. Each treatment was replicated three times.

In the field, two experiments were conducted with oats, one on Ruston sandy loam and the other on Atwood sandy loam. The fertilizer treatments shown in Table 2 were made as a top dressing to the oats which were grown to maturity, harvested, threshed, and weighed. Each treatment was replicated four times.

Also, for 2 years, cotton was grown on Grenada silt loam which had received different fertilizer treatments (Table 3) before planting. All plots were cultivated and harvested alike, and an average yield of seed cotton from the four replications was used in calculating the response from the fertilizer treatments. In all field experiments the fertilizer mixtures were prepared by mixing the proper amounts of nitrogen as nitrate of soda, phosphate as superphosphate, and potash as muriate of potash.

EXPERIMENTAL RESULTS

GREENHOUSE RESULTS WITH OATS

The results given in Table 1 show the effect of different amounts of nitrogen upon the response of oats to phosphorus in the greenhouse. Since the plants were harvested before maturity, only the herbage yields were obtained, and no measure of the grain yields was available. When applied with the lower rates of nitrogen (32 pounds per acre), the phosphate treatments produced only slightly greater yield than the unphosphated treatment. When applied with the higher rate of nitrogen (96 pounds per acre), however, the phosphate treatments increased the yield of oats about 56% over the unphosphated (12–0–8) treatment. When applied without nitrogen or without nitrogen and potash (0–12–8 and 0–12–0), the phosphate treatments produced about the same yield as the unfertilized oats. Plants receiving high and low rates of nitrogen with and without phosphorus are shown in Fig. 1.

TABLE 1.—*Effect of varying amounts of nitrogen upon the response of oats to phosphate in the greenhouse.*

Treatment, 800 lbs. per acre	Average yield per pot, dry tissue, grams	Increased yield due to phosphate, grams	PO_4 in plants, %	Total absorbed PO_4, mgms
N–P–K	—	—	—	—
4–0–8 (no phosphorus)	9.5	—	0.75	72.75
4–4–8	10.5	1.0	1.14	126.54
4–8–8	10.8	1.3	1.32	145.20
4–12–8	11.5	2.0	1.29	144.48
12–0–8 (no phosphorus)	10.5	—	0.80	96.80
12–4–8	16.3	5.8	1.01	156.55
12–8–8	16.1	5.6	1.21	202.07
12–12–8	16.7	6.2	1.34	230.48
0–12–8 (no nitrogen)	4.6	—	1.35	66.15
0–12–0 (only phosphorus)	4.9	0.6	1.31	54.60
No fertilizer	4.3	—	1.21	56.87

An analysis of the oat plants shows no startling difference between the percentage of PO_4 absorbed by plants receiving the high and plants receiving the lower rate of nitrogen. Naturally the larger plants absorbed more total PO_4, but the fact that the percentage of PO_4 in

the plant was not increased by the heavier nitrogen treatment indicates that the increased yield from phosphate with the higher rate of nitrogen must have been due to a better utilization of the PO_4 that was available.

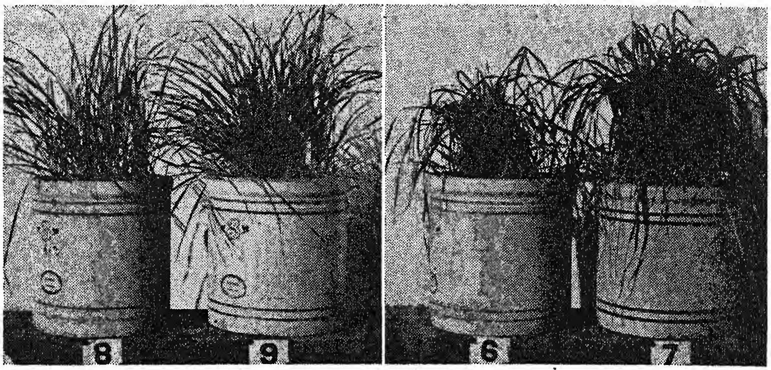


FIG. 1.—Effect of rate of nitrogen application upon the response of oats to phosphorus. The pots on the left received 32 pounds of nitrogen per acre; pot 8, no P_2O_5 (4–0–8); pot 9, 96 pounds of P_2O_5 (4–12–8). The pots on the right received 96 pounds of nitrogen per acre; pot 6, no P_2O_5 (12–0–8); pot 7, 96 pounds of P_2O_5 (12–12–8).

FIELD RESULTS WITH OATS

The results given in Table 2 show the effect of different amounts of nitrogen upon the response of oats to phosphate on Atwood and Ruston sandy loams. An average of the two experiments shows that when applied with 16 pounds of nitrogen per acre, the phosphate treatments (4–4–8 and 4–8–8) produced only 2.5 and 2.6 bushels more

TABLE 2.—*Effect of varying amounts of nitrogen upon the response of oats to phosphate in the field.*

Treatment, 400 lbs. per acre	Yield per acre: Atwood sandy loam, Grain, bu.	Yield per acre: Atwood sandy loam, Straw, lbs.	Yield per acre: Ruston sandy loam, Grain, bu.	Yield per acre: Ruston sandy loam, Straw, lbs.	Average yield of the two fields, Grain, bu.	Average yield of the two fields, Straw, lbs.	Average increase due to phosphate, Grain, bu.	Average increase due to phosphate, Straw, lbs.
N–P–K....	—	—	—	—	—	—	—	—
4–0–8......	13.3	511.4	29.8	1,033.6	21.6	772.5	—	—
4–4–8......	14.4	603.8	33.7	1,229.4	24.1	916.6	2.5	144.1
4–8–8......	13.8	674.6	34.5	1,218.6	24.2	946.6	2.6	174.1
12–0–8.....	20.4	1,011.8	37.7	1,713.6	29.1	1,362.7	—	—
12–4–8.....	28.4	1,206.9	54.4	2,268.5	41.4	1,737.7	12.3	375.0
12–8–8.....	34.5	1,860.5	58.3	2,600.3	46.4	2,230.4	17.3	870.0
0–8–8......	7.1	125.1	20.4	462.4	13.3	293.7	—	—
0–8–0......	7.3	130.6	19.6	609.3	13.0	370.0	0.2	51.8
No fertilizer	6.6	130.6	19.0	505.9	12.8	318.2	—	—

grain per acre, respectively, than the unphosphated (4–0–8) treatment. When applied with 48 pounds of nitrogen, however, the phosphate treatments (12–4–8 and 12–8–8) produced 12.3 and 17.3 bushels more grain, respectively, than the unphosphated (12–0–8) treatment. With the lower rate of nitrogen, 32 pounds of phosphate produced no more grain than 16 pounds of phosphate, but with the higher rate of nitrogen 32 pounds of phosphate produced considerably more grain than 16 pounds of phosphate. These results indicate that if large amounts of nitrogen are applied to the soil in order to obtain maximum yields, oats will require more phosphate.

The response of oat straw to phosphate was somewhat similar to the response of grain. The phosphate treatments produced small increased yields of straw when applied with the lower rate of nitrogen, but when applied with the higher rate of nitrogen the phosphate treatments produced considerably larger yields. When applied without nitrogen or without nitrogen and potash (0–8–8 and 0–8–0), the phosphate treatments produced about the same yield of grain and straw as the unfertilized oats. The data in Tables 1 and 2 suggest strongly that before oats can properly utilize the phosphate applied to many Mississippi soils, the nitrogen content of the soils must be increased.

FIELD RESULTS WITH COTTON

In a 2-year experiment with cotton on Grenada silt loam at Holly Springs, Miss., phosphorus applied with a small amount of nitrogen (16 pounds per acre) gave little or no increase in cotton yields, the 4–4–8 plot yielding only 17 pounds per acre more and the 4–8–8 plot only 30 pounds per acre more than the 4–0–8 (no phosphate) plot (Table 3). However, when phosphorus was applied with 32 or 48 pounds of nitrogen, respectively, it gave a remarkable increase in the cotton yields, the 8–4–8 plot yielding 183 pounds per acre more and the 8–8–8 plot yielding 250 pounds per acre more than the 8–0–8

TABLE 3.—*Effect of varying amounts of nitrogen upon the response of cotton to phosphate in the field.*

Treatment, 400 lbs. per acre	Yield of seed cotton per acre, lbs.	
	2-year average	Increase due to phosphate
N–P–K	—	—
4–0–8	1,115	—
4–4–8	1,132	17
4–8–8	1,145	30
8–0–8	1,121	—
8–4–8	1,304	183
8–8–8	1,371	250
12–0–8	1,192	—
12–4–8	1,333	141
12–8–8	1,407	215
0–8–8	1,096	—
0–8–0	960	—
No fertilizer	964	—

plot. When applied with the lower rate of nitrogen, 32 pounds of phosphate (P_2O_5) as 4–8–8 produced only slightly more yield than 16 pounds of phosphate (4–4–8), but when used with the higher rates of nitrogen, 32 pounds of phosphate (8–8–8 and 12–8–8) produced considerably more cotton than 16 pounds of phosphate (8–4–8 and 12–4–8). These results substantiate the field results with oats by suggesting that if adequate amounts of nitrogen are applied to the soil, cotton will require more phosphate.

DISCUSSION

The fact that many nonleguminous crops do not respond well to phosphate on southern soils which are known to be low in phosphate has baffled agronomists for many years. This problem has been even more puzzling since midwestern soils which are much higher in phosphate than southern soils respond well to applied phosphate. Since certain nonleguminous crops fail to respond to phosphate, it is of economic importance either to reduce the application of phosphate or to obtain a better utilization of that which is applied. Mississippi soils are already extremely low in phosphorus and it does not seem wise to reduce the rate of application.

The present study was initiated in order to determine how plants might better utilize the phosphate applied to southern soils. The results suggest a definite relationship between the amount of nitrogen available to plants and the utilization of phosphorus by cotton and oats. When phosphorus was applied with only small amounts of nitrogen, cotton and oats responded only slightly to phosphate, but when phosphorus was applied with large amounts of nitrogen, both cotton and oats responded well to phosphate.

These results offer a partial explanation of why cotton and oats often fail to respond to phosphate. Undoubtedly the nitrogen content of many southern soils is too low to allow the proper utilization of phosphate, and as long as nitrogen is the limiting element, phosphorus cannot be efficiently utilized by the plants. Even small applications of nitrogen to the soil do not supply enough nitrogen to permit the proper utilization of phosphorus. When adequate amounts of nitrogen are added to the soil, the plant utilizes more phosphate, and therefore, responds to phosphate applications.

At the present time, the average Mississippi farmer who uses fertilizer on cotton and oats does not apply more than 16 pounds of nitrogen, and accordingly, in many cases, he receives no direct benefit from applied phosphate. However, if after the war nitrogen is sold at a considerably reduced price, the farmer will undoubtedly use more nitrogen. If large amounts of nitrogen are applied to the soil, nonleguminous crops will not only respond better to applied phosphate, but will require larger phosphate applications.

At the present time it is probably impractical to apply more than 40 pounds of nitrogen per acre to either cotton or oats. During a year when the boll weevil population is high, large applications of nitrogen delay maturity and thus cause a high boll weevil infestation. Therefore, high rates of nitrogen for cotton may often reduce cotton yields

unless boll weevils are controlled. High rates of nitrogen for oats cause it to lodge badly, and if oats are grown for grain, lodging is often a serious handicap in harvesting.

The results of the investigation, even now, have a practical application. The complete fertilizers commonly used on nonleguminous crops in the South are lower in nitrogen than in phosphorus. In order to obtain a better utilization of the phosphate in complete fertilizers, the ratio of nitrogen to phosphorus should be increased in many cases.

SUMMARY

The effect of nitrogen upon the response of cotton and oats to phosphorus in the case of Mississippi soils was determined by greenhouse and field experiments in which different rates of nitrogen was applied with varying amounts of phosphorus.

There was a definite relationship between the amount of nitrogen available to cotton and oats and their response to phosphorus. Cotton and oats gave only a slight response to phosphorus which was applied with small amounts of nitrogen, but both crops gave a high response to phosphorus which was applied with large amounts of nitrogen. Plants receiving adequate amounts of nitrogen not only respond better to phosphorus, but they also require larger amounts of it.

These results partially explain why many crops do not respond better to phosphorus on southern soils which are low in this element, and they suggest that as long as nitrogen remains a limiting element in these soils, nonlegumes will not respond well to phosphate fertilizer.

LITERATURE CITED

1. Beckenback, J. R., Robbins, W. R., and Shive, J. W. Nutrition studies with corn. Soil Sci., 45:403–426. 1938.
2. Breazeale, J. F. The effect of one element of plant food upon the absorption by plants of another element. Ariz. Agr. Exp. Sta. Tech. Bul. 19. 1928.
3. Dutoit, J. L., and Beater, B. E. Plant food absorption. Proc. 13th Amer. Congress of South Africa Sugar Tech. Assoc., 60–63. 1939. (Chem. Abs., 33:7462. 1939.)
4. Kraybill, H. R. Plant metabolism studies as an aid in determining fertilizer requirements. Jour. Ind. and Eng. Chem., 22:275–276. 1930.
5. Sircar, S. M., and Sen, Nirad Kirmar. Physiology of Rice: Effect of phosphorus deficiency on growth and nitrogen metabolism in rice leaves. Ind. Jour. Agr. Sci., 11:193–204. 1941. (Chem. Abs., 35:7472. 1941.)

INHERITANCE OF STRENGTH OF LINT IN UPLAND COTTON[1]

J. O. WARE AND D. C. HARRELL[2]

RESEARCH laboratories of the textile, tire, and belting industries and of the U. S. Dept. of Agriculture have recognized for some years the importance of strength of cotton lint in wearing apparel, sewing thread, industrial fabrics, belt ducks, and cords or cables for rubber tires. While tensile strength alone may not be as important as other lint properties contributing to appearance in wearing apparel and to fatigue resistance in industrial fabrics, this property must be present in all cotton textiles to the extent that manufacturing processes are not handicapped by undue yarn breakage and the slowing down of other operations dependent on the strength in the lint.

In the cultural standardization of existing cotton varieties and in breeding new varieties and strains due consideration therefore should be given to strength for all uses. Special consideration must be given to this property in those cottons that are to be used in the manufacture of most industrial goods and in all domestic goods requiring yarns of high strength. Soil moisture and other growth factors, when they vary in pronounced manner, greatly modify the inherent strength of the lint. These influences, however, tend to affect this property in all varieties and strains in the same direction and to somewhat the same extent. That is, under any reasonable condition of the environment, a genetically strong stock can be depended on in general to produce stronger lint than a genetically weak stock.

In making a preliminary report of spinning and fiber studies of a uniform variety test consisting of duplicate samples of 16 varieties grown for 3 years and at eight widely scattered locations in the rain belt portion of the cotton growing area of the United States, Campbell (2)[3] pointed out from two of the three year results that strength of yarn and the strength, length, fineness, and maturity of lint are primarily dependent on the variety grown.

A final summary of the data of this series of experiments including the three years of 1935, 1936, and 1937 and consisting of 768 samples will be reported soon, but in brief it shows strength as among five other lint properties to be one of the most important single factors contributing to the skein strength of the yarn spun.

Since tensile strength of lint is an important factor in manufacture and has been shown to be a genetic or varietal characteristic in production, genetic study of the mode of inheritance of this property

[1]Contribution from Division of Cotton and Other Fiber Crops and Diseases, Bureau of Plant Industry, Soils, and Agricultural Engineering, Agricultural Research Administration, U. S. Dept. of Agriculture, and the South Carolina Experiment Station (Pee Dee Experiment Station Branch, Florence, S. C.), cooperating. Received for publication August 18, 1944.

[2]Senior Agronomist, Plant Industry Station, Beltsville, Md.; and Assistant Agronomist, Pee Dee Experiment Station Branch, Florence, S. C., respectively. Mr. Harrell is now in the military service.

[3]Reference by number in parenthesis is to "Literature Cited", p. 987.

becomes important. Some results of such a study are presented in this paper.

MATERIALS AND METHODS

For the purpose of making a study of the inheritance of several characters in upland cotton, *Gossypium hirsutium*, a cross was made between two stocks, Florida Green Seed and Rowden. These stocks differed in length, strength, fineness, and X-ray angle of the lint and in several other plant characters. Length and length uniformity of lint and color of seed fuzz in this cross have been reported already by Ware, Jenkins, and Harrell (4). That publication also supplies a description of the parental material and information about the general procedure of the experiment. The reported results, however, were only through the first backcross and the F_2 generation. In this paper which reports strength of lint the results include an additional year, which provided progenies of the first backcross, a second backcross, and the F_3 generation. The backcrosses reported in this paper as well as those in the former were made to both parental lines.

The Pressley (3) strength tester was used in this study. This instrument breaks a small bundle or ribbon of paralleled fiber, clasped in jaws, and cut to standard length (0.460 inch), and registers the required stress in pounds on its beam. The value found through dividing the number of pounds required to break the evenly cut sample by the milligram weight of this sample after breaking is designated as the *strength index*.[4]

RESULTS AND DISCUSSION

The 9 Rowden, 10 F_1, and 6 Florida Green Seed plants reported in Table 1 were grown in 1939. The *strength index* frequency distribution of the three groups indicates that each belong to separate populations as far as this property is concerned and the means show that the two parental lines, on the average, are separated a little more than 1 unit. The F_1 mean is slightly above the median point of parental levels, or nearer the mean of the stronger parent.

TABLE 1.—*Comparison of F_1 and parental progenies in 1939.*

Stock	Mean of observations in frequency	Strength index by class intervals								Number of plants
		5.50	5.75	6.00	6.25	6.50	6.75	7.00	7.25	
Rowden	5.76	3	4	1	1	–	–	–	–	9
F_1	6.38	–	–	2	3	3	2	–	–	10
Florida Green Seed	6.85	–	–	–	–	1	2	2	1	6
Mean between parents	6.30	–	–	–	–	–	–	–	–	—

The 21 Rowden, 22 F_1, and 23 Florida Green Seed plants shown in Table 2 were grown in 1940. The frequency distribution in this case also indicates distinct populations, but the F_1 group overlaps more of the range of the Rowden group than that of the other parental line. The mean was near that of the Rowden or the parent of lower strength.

[4]These determinations were made under the supervision of D. M. Simpson, Agronomist, in charge of the U. S. Cotton Field Station Laboratory, Knoxville, Tenn.

TABLE 2.—*Comparison of F_1 and parental progenies in 1940.*

Stock	Mean of observations in frequency	Strength index by class intervals											Number of plants
		5.75	6.00	6.25	6.50	6.75	7.00	7.25	7.50	7.75	8.00	8.25	
Rowden	6.24	1	6	5	8	1	—	—	—	—	—	—	21
F_1	6.61	—	—	4	6	9	3	—	—	—	—	—	22
Florida Green Seed	7.46	—	—	—	—	2	1	6	10	2	1	1	23
Mean between parents	6.85	—	—	—	—	—	—	—	—	—	—	—	—

Since the F_1 mean (with reference to the median of the two parental means) shifted somewhat in the 2-year period, the F_1 and parental comparison was repeated the year following, or in 1941. Five Florida Green Seed plants had been pollinated by one Rowden plant in 1940. This material was grown in 1941 and the data are reported in Table 3. Eleven progeny plants from the Rowden plant used for pollen in the five crosses were tested for strength. Also, 55 plants coming from five sibs of the Rowden parental plant were tested. Although the 11 plants do not demonstrate as much frequency spread as the 55 plants, the former group is within the range of the latter and has practically the same mean level as the larger or progeny group from the sibs. The two groups, therefore, are combined in the summary of Table 3.

The separate frequency distributions of the five Florida Green Seed parental progenies vary somewhat and the means range from 6.55 to 7.07. On combining the five Florida Green Seed frequencies a fairly smooth curve is formed, with the exception of one plant at each end considerably out of range. In the 1939 and 1940 growths, the *strength index* means of Rowden and Florida Green Seed were somewhat more than a unit apart, while in the 1941 growth they were about three-fourths of a unit apart, as shown in the summary of Table 3. The frequency distributions of the summary also show the three populations to be somewhat less distinct than in the two previous years. The mean of the 53 F_1 plants is somewhat above the median of the two parental groups. This relation, however, varies among the five crosses. In cross B, the mean of the F_1 practically coincides with the median of the two parental means. In crosses C, D, and E the mean of the F_1 in each case is somewhat above the median level of the parents. In cross A, however, the mean of the F_1 practically equals that of the Florida Green Seed parental line.

In the second column of Table 3, the 1940 mean of each plant used in the crosses is given. It will be noted that the 1941 *strength index* level is lower than that of 1940, but that except in case of the Florida Green Seed plant used in cross E the higher 1940 levels are reflected in the 1941 levels.

BACKCROSSES

Backcrosses were made to both parental lines in 1939. Three F_1, one Rowden, and one Florida Green Seed plants were used. The *strength*

TABLE 3.—*Comparison of F_1 and parental progenies in 1941.*

Stock	Mean of 1940 plants used	Mean of observations in frequency	Strength index by class intervals 4.75	5.00	5.25	5.50	5.75	6.00	6.25	6.50	6.75	7.00	7.25	7.50	7.75	8.00	8.25	Number of plants
Rowden																		
Parent of Crosses	6.55	5.98	–	–	1	–	1	8	1	–	–	–	–	–	–	–	–	11
Five Sibs	6.61	6.01	2	1	–	4	9	14	19	3	3	–	–	–	–	–	–	55
Cross A																		
F_1	(7.22) (6.55)	6.53	–	–	–	1	–	–	4	–	3	–	2	–	–	–	–	10
Florida Green Seed	7.22	6.55	–	–	–	–	–	2	1	2	3	–	1	–	–	–	–	9
Mean between parents		6.26																
Cross B																		
F_1	(7.37) (6.55)	6.24	–	1	–	–	2	–	4	1	–	1	–	1	–	–	–	10
Florida Green Seed	7.37	6.55	–	–	1	–	–	1	2	1	2	1	2	1	–	–	–	11
Mean between parents		6.26																
Cross C																		
F_1	(7.59) (6.55)	6.55	–	–	–	–	–	–	2	4	5	–	–	–	–	–	–	11
Florida Green Seed	7.59	6.75	–	–	–	–	–	1	–	4	3	1	1	1	–	–	–	11
Mean between parents		6.36																
Cross D																		
F_1	(7.59) (6.55)	6.65	–	–	–	–	–	–	2	2	4	3	–	–	–	–	–	11
Florida Green Seed	7.59	7.07	–	–	–	–	–	–	1	1	3	1	3	1	–	–	1	11
Mean between parents		6.52																
Cross E																		
F_1	(8.32) (6.55)	6.40	–	–	–	1	–	1	4	2	2	1	–	–	–	–	–	11
Florida Green Seed	8.32	6.69	–	–	–	–	–	1	1	3	2	2	2	–	–	–	–	11
Mean between parents		6.33																
Summary																		
Rowden	6.60	6.00	2	1	1	4	10	22	20	3	3	–	–	–	–	–	–	66
F_1	(7.62) (6.60)	6.47	–	1	–	2	2	1	16	9	14	5	2	1	–	–	–	53
Florida Green Seed	7.62	6.72	–	–	1	–	-	5	5	11	13	5	9	3	–	–	1	53
Mean between parents		6.36																

index data from the progenies of the five plants and the backcrosses themselves (four BC groups) are reported in Table 4. The mean of the 17 Rowden plants and the 23 Florida Green Seed plants are about 1 unit apart, but the frequency distribution of the two groups overlaps only in one class interval. The three groups of F_2 showed some difference as to breadth of segregation and level of mean. The backcross of Rowden on plant 1 of F_1 exhibited a mean level close to the level of the F_2 mean (from plant 1) and the progeny of the Rowden, the three not being over 0.14 unit apart. However, the frequency distribution of the F_2 was wide and that of the Rowden narrow. The recurrent parent apparently had considerable effect in narrowing the frequency range in the backcross. The backcross of Rowden on plant 2 of the F_1 behaved similarly to a regular F_1 with respect to its parents. The F_2 (from plant 2) was practically as stable as a parental line and the mean of the backcross was slightly above the median point between the F_2 mean and the mean of the line from the recurrent parent. Plant 2 of the F_1 also was backcrossed to the Florida Green Seed plant. This combination forms a direct comparison of the influence of the two recurrent parents in backcrosses. As noted above, the means of the two recurrent parental lines differ by about a whole unit. The means of the opposite backcrosses are about ½ unit apart. The mean of the backcross to Florida Green Seed was slightly above the median point between that of F_2 and the progeny of the recurrent parent.

The recurrent Rowden parent did not lower the *strength index* as much as the recurrent Florida Green Seed parent raised *strength index*. On the other hand, the recurrent Florida Green Seed parent when backcrossed to plant 3 of the F_1 did not raise the resulting backcross mean. This backcross mean was somewhat lower than that of the F_2 coming from plant 3. However, since the level of strength in this F_2 is in the upper range of the general F_2 population (Table 6) it would not be expected that the recurrent parent would advance the strength much further.

PROGENY OF BACKCROSSES AND SECOND BACKCROSSES

Plants in the backcross generation were re-backcrossed to respective recurrent parental line plants in 1940. The selfed and crossed seed of the plants used were planted in 1941. The *strength index* data of this growth are reported in Table 5. For comparison the progenies of the Rowden plant and the Florida Green Seed plant and the respective sibs of these two plants are reported at the top of the table. It will be noted that the *strength index* means of the progenies of the two recurrent parents are 0.61 unit apart and that the mean difference between the two sib groups are 0.76 unit apart. The frequency distribution of each of the two recurrent parental lines indicates that the plant used in both cases is fairly representative of the larger groups of plants from the sibs. The 1940 means of the two recurrent parental plants are about 1 unit apart while the means of the respective sib progenies are about ¾ unit apart.

In the summary of Table 5 it is shown that the mean of the 12 plants used here from the first backcross to Rowden is 6.67 and the

TABLE 4.—*Comparison of backcrosses to Rowden and to Florida Green Seed in 1940.*

Stock	Mean of observations in frequency	Strength index by class intervals															Number of plants
		4.75	5.00	5.25	5.50	5.75	6.00	6.25	6.50	6.75	7.00	7.25	7.50	7.75	8.00	8.25	
Rowden	6.48	—	—	—	—	—	1	4	8	4	—	—	—	—	—	—	17
Florida Green Seed	7.46	—	—	—	—	—	—	—	—	2	1	6	10	2	1	1	23
F_2 (F_1 plant 1)	6.54	1	1	—	1	—	2	—	5	5	5	2	—	1	—	—	23
BC to Rowden	6.40	—	—	—	—	2	—	2	4	1	1	—	—	—	—	—	10
F_2 (F_1 plant 2)	6.77	—	—	—	—	—	—	1	2	4	1	1	1	—	—	—	10
BC to Rowden	6.68	—	—	—	—	—	1	—	2	5	3	—	—	—	—	—	11
BC to Florida Green Seed	7.19	—	—	—	1	—	—	—	1	—	3	3	1	1	2	—	12
F_2 (F_1 plant 3)	7.01	—	—	—	—	—	—	—	6	7	8	6	3	3	—	—	33
BC to Florida Green Seed	6.81	—	—	—	—	—	1	—	3	2	2	2	1	—	—	—	11

TABLE 5.—*Comparison of progeny of backcrosses to Rowden and to Florida Green Seed and second backcrosses to respective recurrent parents in 1941.*

Stock	1940 plants used		Mean of observations in frequency	Strength index by class intervals													
	No. of plants or crosses	Mean		4.75	5.00	5.25	5.50	5.75	6.00	6.25	6.50	6.75	7.00	7.25	7.50	7.75	Number of plants
Rowden																	
Parent of 2nd backcross...	1	6.55	5.98	–	–	1	–	1	8	1	–	–	–	–	–	–	11
Sibs of parent.........	5	6.61	6.01	2	1	–	4	9	14	19	3	3	–	–	–	–	55
Florida Green Seed																	
Parent of 2nd backcross..	1	7.58	6.59	–	–	–	–	–	1	1	2	3	2	–	–	–	9
Sibs of parent.........	6	7.39	6.77	–	–	1	–	–	5	6	14	19	14	10	4	2	75
Combination AR																	
$(F_1 \times Rowden)_2$..........	4	6.74	5.97	1	2	4	3	6	9	10	4	3	–	–	–	–	42
$(F_1 \times Rowden)$ Rowden...	2	(6.56) (6.55)	6.17	–	–	1	–	3	6	6	1	–	3	–	–	–	20
Combination AF																	
$(F_1 \times$ Florida Green Seed$)_2$	1	7.03	6.64	–	–	–	–	2	3	2	9	6	6	5	–	–	33
$(F_1 \times$ F.G.S.) F.G.S.......	1	(7.03) (7.58)	6.64	–	–	–	–	–	–	2	2	3	2	–	–	–	9
Combination BR																	
$(F_1 \times Rowden)_2$..........	2	6.85	6.32	–	1	–	–	2	3	2	7	3	2	–	–	–	20
$(F_2 \times Rowden)$ Rowden...	2	(6.85) (6.55)	6.02	–	1	–	4	3	3	8	2	1	–	–	–	–	22
Combination BF																	
$(F_1 \times$ Florida Green Seed$)_2$	2	6.99	6.77	–	–	–	–	1	1	3	4	7	8	5	1	–	30
$(F_1 \times$ F.G.S.) F.G.S.......	2	(6.99) (7.58)	6.99	–	–	–	–	–	–	2	1	5	4	7	3	–	22

Combination CR																	
(F_1×Rowden)$_2$..........	3	6.50	6.41	–	–	1	–	2	7	8	11	5	6	1	–	–	41
(F_1×Rowden) Rowden...	3	(6.50) (6.55)	5.62	1	2	5	7	7	7	2	–	–	–	–	–	–	31
Combination CF																	
(F_1×Florida Green Seed)$_2$	2	7.93	6.83	–	–	–	–	–	2	4	7	10	9	8	2	1	43
(F_1×F.G.S.) F.G.S.......	2	(7.93) (7.58)	6.63	–	–	–	–	–	1	6	5	4	3	3	–	–	22
Combination DR																	
(F_1×Rowden)$_2$..........	3	6.68	6.67	–	–	1	1	2	1	7	12	16	3	6	3	1	53
(F_1×Rowden) Rowden...	2	(6.75) (6.55)	5.97	–	–	–	2	7	9	4	1	–	–	–	–	–	23
Combination DF																	
(F_1×Florida Green Seed)$_2$	2	6.74	6.84	–	–	–	–	–	–	–	7	6	2	5	1	–	21
(F_1×F.G.S.) F.G.S.......	2	(6.74) (7.58)	6.44	–	–	–	–	2	5	2	5	3	5	–	–	–	22
Combination EF																	
(F_1×Florida Green Seed)$_2$	2	7.17	7.13	–	–	–	–	–	–	1	1	5	4	2	6	3	22
(F_1×F.G.S.) F.G.S.......	2	(7.17) (7.58)	6.92	–	–	–	–	–	–	–	2	6	11	3	–	–	22
Summary																	
(F_1×Rowden)$_2$..........	12	6.67	6.37	1	3	6	4	12	20	27	34	27	11	7	3	1	156
(F_1×Rowden) Rowden...	–		5.91	1	3	6	13	20	25	20	4	1	3	–	–	–	96
(F_1×Florida Green Seed)$_2$.	9	7.26	6.82	–	–	–	–	3	6	10	28	34	29	25	10	4	149
(F_1×F.G.S.) F.G.S.......	–		6.74	–	–	–	–	2	6	12	15	21	25	13	3	–	97

mean of the nine plants taken from the first backcross to Florida Green Seed is 7.26. These means are 0.59 unit apart. The means of the respective progeny group grown in 1941 are 6.37 and 6.82, or 0.45 unit apart. The offspring of the second backcrosses indicate that the opposite recurrent parents influenced further separation of the *strength index* means. The mean of the backcross, twice to Rowden, is 5.91 and the mean of the backcross, twice to Florida Green Seed, is 6.74, a difference of 0.83 unit. The Rowden 1940 mean being somewhat lower than the mean of the first backcross, the second backcross mean was reduced below the mean of the progeny of the first backcross (to Rowden). Although the Florida Green Seed mean was higher than the mean of the first backcross (to Florida Green Seed), the second backcross was not higher than the mean of the progeny from the first backcross. The Florida Green Seed recurrent parent did not increase the strength as the Rowden recurrent parent decreased strength. In Table 5 the backcrosses to Rowden are separated into four groups or combinations and the backcrosses to Florida Green Seed are separated into five groups or combinations. These combinations are alternated in the table to show contrast more clearly. The frequency distributions demonstrate the trend or shift caused by the first and second backcrosses toward the opposite recurrent parents. In three of the four Rowden backcross combinations, the recurrent parent lowered the mean of the second backcross. The exception was the AR combinations in which the reverse was true. Of the five Florida Green Seed backcross combinations one, combination BF, showed the mean of the second backcross to be higher than the progeny of the first backcross. In the case of another, combination AF, the means of the two groups were even.

F_2 AND F_3 GENERATIONS

The F_2 generation was grown in 1940 and the F_3 generation in 1941. Lines of both parents were grown along with these generations for comparison. These parental lines were also made use of in the F_1 crosses and in the backcrosses grown in corresponding years and already discussed. The F_2 and F_3 and the parental lines are reported in Table 6. The F_2 group includes the progeny of an additional F_1 plant not reported in Table 4. The F_2 generation plants, with the exception of 3 out of the 87, range within the limits of the combined range of the two parental lines. The two parental distributions overlap only in one class interval which is the modal class of the F_2. The means of the two parental lines are a little more than 1 unit apart and the mean of the F_2 is slightly above the median point between the two parental means. With the exception of the three low plants, the F_2 does not exhibit wide fluctuation in *strength index*.

The two parental lines in 1941, however, do not show as clear cut distinction as in 1940. The frequency distributions are wider, overlap considerably, and the means are only 0.86 unit apart. However, when more plants are included, as was the case in 1941, there was more opportunity to exhibit variation. Also, in progenies of sibs there is more opportunity for variation than may be exhibited by the sibs them-

TABLE 6.—*Comparison of F_2 and F_3 generations and parental strains in 1940 and 1941.*

Stock	1940 plants used			Amount above 1941 mean	Mean of observations in frequency	Strength index by class intervals																	Number of plants
	Class center	Number planted	Mean			4.25	4.50	4.75	5.00	5.25	5.50	5.75	6.00	6.25	6.50	6.75	7.00	7.25	7.50	7.75	8.00	8.25	
Section A, 1940 Growth																							
Rowden parental strain	—	3	—	—	6.35	–	–	–	–	–	–	1	7	9	16	5	–	–	–	–	–	–	38
Florida Green Seed parental strain	—	1	—	—	7.46	–	–	–	–	–	–	–	–	–	–	2	1	6	10	2	1	1	23
F_2 generation	—	4	—	—	6.86	–	–	1	1	–	1	–	2	1	14	23	19	14	7	4	–	–	87
Section B, 1941 Growth																							
Rowden parental strain	—	11	6.42	0.51	5.91	–	–	3	1	4	16	23	41	25	4	3	–	–	–	–	–	–	120
Florida Green Seed parental strain	—	7	7.41	0.64	6.77	–	–	–	–	1	–	–	6	7	16	22	16	10	4	2	–	1	85
F_3 Generation																							
Progenies A	6.50	6	6.49	0.34	6.15	2	–	–	1	3	5	15	22	16	18	8	6	2	–	–	–	–	98
Progenies B	6.75	8	6.76	0.39	6.37	1	1	–	–	1	4	9	7	15	9	14	8	3	1	2	–	–	75
Progenies C	7.00	6	7.00	0.35	6.65	–	–	1	–	–	–	1	9	10	14	20	8	5	5	1	–	–	74
Progenies D	7.25	4	7.20	0.40	6.80	–	–	–	1	1	1	2	2	9	7	12	14	13	8	2	–	–	72
Progenies E	7.50	4	7.45	0.66	6.79	–	–	–	–	1	2	1	2	5	4	3	7	9	3	2	–	–	39
Progenies F	7.75	2	7.67	0.80	6.87	–	–	–	–	3	–	1	3	1	–	5	9	–	6	1	1	2	32

selves. The plants selected for producing the F_3 generation were drawn from F_2 class intervals ranging from 6.50 to 7.75.

In the lower portion of Table 6, these F_3 plants are divided into six groups (A to F, inc.) in accordance with source as to F_2 class interval. For these groups the F_2 class center, the number of F_2 plants used, the actual 1940 means of these plants, the 1941 frequency distribution, and the mean of frequencies are shown. The drop in the 1941 mean over that of the 1940 plants seeded is also shown in one of the columns. With the exception of four plants, the entire F_3 population is within the limits of the combined ranges of the parental distributions. The F_3 distribution as a whole extended two class intervals further on each side than that of the F_2 generation, but of the separate F_3 groups, none were more widely spread than the F_2 except the progenies B group. Inspection of the frequencies and the modal class of the six F_3 groups indicates, with the exception of progenies F, that *strength index* in the F_3 is lower than in the F_2 when the latter is considered as a group. The decrease in the level is also indicated by comparing the mean of the F_2 plants seeded and their progenies. In general, the higher the class interval mean of the F_2 plants the more the F_3 group dropped. The generally lower level of strength in 1941 is shown in all material and doubtless is attributed to more unfavorable growing conditions in 1941 than in 1940.

The degree of dominance or recessiveness in strength of lint is important in that knowledge of this behavior is very useful in handling breeding material. General dominance or recessiveness is determined in the F_1 generation, but the complexity of such expressions or the degree of stabilty that might be re-established after crossing plants of different levels of strength is determined by growth of subsequent generations and backcrossing. In these results, strength as recorded by the strength index value appears to be weakly dominant. The F_1 was above the median point of the two parents in the cross of 1939 and in four of the five crosses in 1941. The other cross in 1941 showed the F_1 mean to be about the same as the median level of the two parents. However, in 1940, the F_1 was somewhat below the median level of the two parents.

Berkley and Woodyard (1) pointed out that correlation exists between X-ray diffraction patterns and strength (Chandler method) of cotton lint. The smaller the reading of the angle measurements used by them, the greater the strength. These workers made X-ray measurements on the 1940 growth of three Florida Green Seed plants, four Rowden plants, and two F_1 plants. The mean of angles of the Florida Green Seed was 26.9, of the Rowden 29.9, and of the F_1 28.1. The angle average of the F_1, it will be noted, is slightly closer to the average of the stronger parent.

The effect of the respective recurrent parents on the backcross might be observed also as a measure of dominance or recessiveness. A dominant character occurring in relatively pure form in the recurrent parent would tend to reduce variability of the character expression in highly variable material backcrossed to this parent.

In the first backcrosses of 1940 the Rowden (weaker parent) appeared to have some more stabilizing effect on the frequency distribu-

tions than the Florida Green Seed. On the other hand, the Florida Green Seed side (Table 5) of the 1941 backcross progeny and re-backcross frequencies showed less fluctuation than was demonstrated by the same type of material on the Rowden side. It has already been pointed out in the F_1 study that Rowden tended to be dominant in 1940 and Florida Green Seed in 1941.

SUMMARY AND CONCLUSIONS

F_1, F_2, and F_3, first generation backcrosses, and second generation backcrosses were grown from a Florida Green Seed and Rowden cross. Parental lines were grown along with these hybrid groups also and made use of in re-crossing and in backcrossing. The F_1 generation was repeated in the second and third years. The first backcross was made with the F_1 in 1939 to both parental lines. In 1940 plants in the respective first generation backcrosses were backcrossed again to corresponding recurrent parental plants. The Florida Green Seed stock had the higher *strength index* which was approximately 1 unit higher than in the Rowden. *Strength index* determinations were made on this material by use of the Pressley strength tester.

In obtaining measurements of the heredity of strength, results varied somewhat, but averages indicate that the inheritance is intermediate with slight tendency to weak dominance. This behavior is such that in repeated backcrossing the level of strength is easily shifted in either direction.

Strength in F_3 progenies from plants selected out of the several F_2 class intervals did not in any case exhibit as much uniformity as shown by either parent, but these F_3 plants tended to maintain the F_2 level of origin.

Seasons affected strength to some degree. In 1939 and 1941 the respective parental lines were at approximately the same level, but higher in 1940. In the several hybrid groups the 1941 level was lower than the 1940 level. Although environment was a factor in this study and doubtless contributed considerably to the expression of variability and in changing season mean levels, the yearly combination or set-up was such that reliable genetic measures appear to have been obtained.

LITERATURE CITED

1. BERKLEY, E. E., and WOODYARD, O. C. A new microphotometer for analyzing X-ray diffraction patterns of raw cotton fiber. Ind. and Eng. Chem., 10: 451–455. 1938.
2. CAMPBELL, M. E. Preliminary report of cotton spinning and related fiber studies, in connection with the regional variety series, crops of 1935 and 1936. Address before American Society Agronomy, New Orleans, La., November 23, 1939. (Mimeographed.)
3. PRESSLEY, E. H. A cotton fiber strength tester. Amer. Soc. Testing Material Bul., Oct., 1942: 13–17. 1942.
4. WARE, J. O., JENKINS, W. H., and HARRELL, D. C. Inheritance of green fuzz, fiber length and fiber length uniformity in upland cotton. Jour. Amer. Soc. Agron., 35:382–392. 1943.

ABSTRACTS OF PAPERS

Which Were to Have Been Presented
At The Annual Meetings
Of The

AMERICAN SOCIETY OF AGRONOMY

And The

SOIL SCIENCE SOCIETY OF AMERICA

CROPS SECTION

MANY of the papers which were to have been presented before the Crops Section of the American Society of Agronomy will be submitted for consideration for publication in this JOURNAL, and their abstracts are not included here. In most cases, the program for 1944 will be presented as previously planned at the meetings in 1945. Consequently abstracts of these papers also are not included.—I. J. JOHNSON, *Chairman, Crops Section.*

CORN BREEDING

Gamete Selection in Corn Breeding.—L. J. STADLER, *U. S. Dept. of Agriculture, Columbia, Mo.*

GENERAL corn breeding experience and method experiments indicate that (1) selection for yield genotype is practically effective only on the basis of progeny tests, (2) yield genotype is determined in the main by numerous dominant factors of additive effect, and (3) the present elite lines are the descendants of foundation plants which probably were practically equal to them in level of yield genotype. The establishment of these lines has been in effect the isolation of single genotypes of high yield potential from the varietal populations. The order of frequency of genotypes approximating this level among plants of the open-pollinated varieties is the major factor determining the relative efficiency of methods for the further improvement of the plant.

The limited data available indicate rather high variability in yield potential among the plants of open-pollinated varieties, σ averaging about 9% of the mean yield, after correction for variability due to experimental error. The distribution of yield potentials in these populations is normal. This indicates that plants equal in yield potential to the elite lines are not extremely rare in the common varieties. Exceptional plants of the varietal population, identified by direct testing and used as foundation individuals, may be further improved in yield genotype by a repetition of test-controlled selection in S_1, since genetic variability is at its maximum in this generation.

Practical limitations of direct extraction of new lines from the varieties are chiefly the following: (1) The frequency of high yield-geno-

types is low enough to make their identification less economical than the identification of comparable genotypes in populations of certain other types now available. (2) The exceptional genotypes identified are virtually unselected as regards characters other than yield. The frequency of genotypes comparable to the elite lines in both yield potential and general agronomic value is probably too low to make their direct extraction feasible as a general practice. The need for new breeding stocks however makes further sampling of the varieties imperative.

By making the gamete the unit of selection, difficulties due to low frequency may be minimized. The yield potential of a plant is the result of dominant additive genes from two parental gametes. Among the open-pollinated plants each individual represents the union of two unselected gametes. In a variety in which 1% of open-pollinated plants attain a desired level of yield potential, gametes of correspondingly high level must constitute almost 10% of the gametic population. The best 1% among gametes represent a level expected to occur among open-pollinated plants at a rate of about 1 in 10,000.

Though individual gametes cannot be directly tested, it is possible to compare them in combination with the constant genotype contributed by the gametes of an inbred line. The method suggested is the direct testing of individual plants of a variety $\times$ inbred-line F_1, followed by a similar test-controlled selection in the S_1 of exceptional plants.

As compared to a similar technic applied to varietal populations, the method has the following advantages: (1) Increased frequency of the exceptional genotypes from the varietal population, with greatly increased frequency of the most exceptional types. (2) Improved control of important characters other than yield. Any individual selected from the top-cross population is at least heterozygous for all desirable factors contributed by the inbred parent. The inbred would ordinarily be selected to insure the presence of the most essential of these characters. (3) Increased possibilities of further improvement by selection in S_1. The scanty evidence now available indicates that genetic variability in yield potential is low in S_1 populations of varietal individuals. It is ordinarily high in F_2 populations from crosses of unrelated inbred lines. The S_1 of the top-cross plants would be comparable to the F_2 of unrelated lines.

Recurrent Selection For Specific Combining Ability in Corn.—FRED H. HULL, *Florida Agricultural Experiment Station, Gainesville, Fla.*

RECURRENT selection in a crossbred lot of corn for combining ability with a specific homozygous line is proposed for building a high complementary relation and improvement of hybrid yield. Such selection is between the genotypes aa and aA or between aA and AA at each locus, not between genotypes aa, aA, and AA at each locus as in current practice. Where the aA effect is essentially equal to the AA effect and the homozygous line is aa, selection for A in the crossbred lot will not be confused by dominance. If the homozygous

line is AA, selection in the crossbred lot will be ineffective and unnecessary.

The fact that nearly all homozygous lines of corn yield less than half of their hybrids strongly suggests frequent excess of aA effects above AA effects. Where such excess occurs current breeding practice will be inefficient in second or later cycles. In the new plan selection at those loci will favor whichever allele is more favorable in combination with the one fixed in the homozygous line. It will continue fully effective through recurring cycles.

BREEDING, GENETICS, AND CYTOLOGY

The Value Of Self-compatibility in Breeding White Clover.—SANFORD S. ATWOOD, *Cornell University, Ithaca, N. Y.*

FROM genetic studies of self-compatibility in white clover, it was concluded that the S_f gene may be very useful in facilitating inbreeding. It was also recognized, however, that with the small amounts of natural crossing obtained on plants bearing this factor, the combining of self-compatible lines on an extensive scale would not give adequate crossing for most practical breeding purposes without first eliminating the S_f gene by controlled matings. In order to understand better some of the behavior factors which will condition the ultimate method of utilizing the S_f gene, data have been collected from four lines of investigation as follows:

1. In a heterozygous S_f plant, the two types of gametes were produced in approximately equal numbers, at least following macrosporogenesis, but when pollen from such a plant was placed on a stigma bearing two other alleles, the S_f pollen functioned to produce less than one quarter of the resultant progeny.

2. When a heterozygous S_fS_x plant was crossed as male onto a self-incompatible plant bearing S_x, the S_x pollen was inhibited completely, despite its association with S_f.

3. In a heterozygous S_fS_x plant, used as female, the S_f functioned as a partly dominant factor when all pollen normally would have been inhibited (S_xS_x), permitting some seed set, but the oppositional effect was not disturbed by S_f when only part of the pollen was inhibited (S_xS_y).

4. Following selfing or intercrossing of heterozygous S_f plants, homozygous S_fS_f individuals were obtained in expected frequencies, and they were detected easily by a progeny test. Such homozygous plants may prove very useful in breeding operations since the few tested so far have imparted considerable vigor and good seed setting ability to their F_1 progenies.

Intra-varietal Crossing in Wheat.—J. B. HARRINGTON, *University of Saskatchewan, Saskatoon, Sask., Canada.*

WHEN two wheat varieties are crossed, heterosis usually occurs, the amount depending upon the extent of the germinal difference between the parents. Since heterosis may be expected in ordinary intra-specific crosses and since any recommended variety

of wheat may be considered a population of biotypes which differ from one another in genetic constitution, it could be reasoned that such a variety might show heterosis if crossed within itself.

A study was made of heterosis as expressed by yield of grain in two intra-varietal wheat crosses. Replicated plot tests of the rod row type were made in F_1 in 1939 (using the seed produced on the plants used as the female parents). Reliance × Reliance F_1 yielded 52.0 bushels per acre, whereas Reliance yielded 44.2 bushels, the difference being highly significant. Marquis × Marquis F_1 yielded 43.8 bushels compared with 43.9 bushels for Marquis.

The F_1 results were so striking that a further intra-varietal cross was added to the study. Two generations in the greenhouse brought it abreast of the other crosses. Replicated plot tests were made of F_2 in 1940, of F_3 in 1941 and 1942, of F_4 in 1942 and 1943, and of F_5 in 1943, using bulk unselected seed throughout.

The results showed significant heterosis in Reliance × Reliance and in Apex × Apex, but no heterosis in Marquis × Marquis. In R × R the yields if the hybrids in percentage of Reliance were 114 in F_2, 110 in F_3, 112 in F_4, and 113 in F_5. In A × A the yields of the hybrids in percentage of Apex were 119 in F_2, 123 in F_3, 104 in F_4, and 103 in F_5. In M × M the comparable figures were 101 in F_2, 109 in F_3, 94 in F_4, and 100 in F_5. Only the R × R cross showed a significantly higher yield than the parental variety for the four generations. However, in A × A the results suggest a falling off of hybrid vigor after F_3, which is to be expected. The apparent maintainance of hybrid vigor in R × R through F_4 and F_5 was not expected.

Of the three varieties used in this study Marquis has been re-selected twice on a pure line basis, the first time being when it was about F_{15}. It should therefore be fairly homozygous. Apex was re-selected in F_7 and Reliance has not been re-selected since the time of its introduction into Saskatchewan in 1925. As far as the writer knows this stock of Reliance was probably bulked in F_4 or F_5 and still contains the heterogeneity of biotypes which would normally be present after only 3 or 4 years of selfing.

The results in general are consistent with expectation and raise important questions for the consideration of plant breeders and specialized seed growers. The study will be continued and expanded in order to furnish answers to some of these questions.

Inheritance and Interaction of Genes Governing Reaction to Stem Rust, Leaf Rust, and Powdery Mildew in a Spring Wheat Cross.—D. G. WELLS, AND S. P. SWENSON, *State College of Washington, Pullman, Wash.*

The F_2, F_3, and F_4 progeny of a cross between a hard red spring wheat selection of H44–Reward × Baringa and a soft white spring wheat selection of Hard Federation × Dicklow were studied for reaction to stem rust, leaf rust, and powdery mildew. For convenience, the parents are referred to as HRB and HFD, respectively. HRB was moderately resistant to stem rust and thus did not have the full resistance of H44. However, it had the resistance of H44 to leaf rust

and powdery mildew. HFD was highly susceptible to all three diseases.

Powdery mildew occurred naturally in the nursery. Epiphytotics of the rusts were induced by introducing two prevalent physiologic races of stem rust and four of leaf rust. Two or three gene pairs appeared to govern reaction to stem rust. Single gene pairs, *Lm lm* and *Ms ms*, appeared to govern reaction to leaf rust and powdery mildew, respectively. From analyses for associations between genes for reaction to these three diseases, a cross-over value of $20.8 \pm 2.0\%$ was found between the leaf rust and mildew genes. Significant linkage relationships were found for the associations stem rust *vs.* leaf rust and stem rust *vs.* mildew, but these two linkages have not been corroborated by subsequent data from a related cross.

PASTURE MANAGEMENT IN THE SOUTHERN STATES

Nitrogen Fertilization of Bermuda Grass Pastures.—O. E. SELL, *Georgia Agricultural Experiment Station, Experiment, Ga.*

THREE rates of nitrogen, 32, 64, and 128 pounds per acre, were applied to bermuda grass pastures with and without phosphate, potash, or limestone. In the first years, greater increased dry matter production per pound of nitrogen applied was obtained as the rate of nitrogen fertilization was increased. This trend was later reversed. Phosphorus, potash, and lime became more important as limiting factors the longer nitrogen was used and the higher the level of nitrogen fertilization. Available phosphorus and potash in the soil was much reduced by nitrogen without mineral fertilization and increasingly so with the higher rates of nitrogen fertilization. Single applications of nitrogen in early summer increased production about as much as when two-split applications were made. Three split-applications gave distinctly less increased production but gave slightly better seasonal distribution of production.

Increased bermuda grass production resulting from nitrogen fertilization was found to be due in part to an increase in number of leaf shoots per unit area of pasture and in part to increase in size and weight of each leaf shoot. The protein content in bermuda grass in one season was increased 11.1, 17.2, and 26.2%, respectively, by 32, 64, and 128 pounds of nitrogen per acre; however, such effects of nitrogen depended upon grazing or clipping the grass at the proper growth stages. In some instances there was an apparent nitrogen recovery in plant growth of better than 100% of the nitrogen applied, probably due to winter-spring clovers grown in association with the grass.

Winter clovers grown on grass sod are undoubtedly the cheapest source of nitrogen. Good winter clover growth has stimulated summer grass growth as much as 64 pounds of nitrogen fertilizer. Nitrate of soda generally increased production more than other commercial fertilizers. Nitrogen fertilization of bermuda grass was distinctly profitable, although greater returns per dollar invested in fertilizers was obtained with phosphorus and limestone due to stimulation of winter clovers. Certain pasture and cattle management problems occur as a result of nitrogen fertilization of pastures.

The Improvement of Carpet Grass Pastures by Fertilization and Seeding to Clover.—E. L. MAYTON, *Alabama Agricultural Experiment Station, Auburn, Ala.*

THE results of several cooperative pasture fertilizer experiments in the carpet grass area of Alabama are presented. This area roughly corresponds to the Lower Coastal Plains portion of the state. The soils are predominantly sandy and carpet grass comes in naturally in open areas of bottom lands. Efforts toward improvement of carpet grass pastures have been directed toward the establishment of spring clovers in the sod to provide earlier grazing and to furnish nitrogen for the stimulation of the carpet grass.

The results of fertilizer treatments definitely show that applications of lime, phosphate, and potash are necessary for the best establishment and growth of clovers. In general, there is a growth response to increasing applications up to 2 tons of lime per acre and to increasing phosphate applications up to 1,200 pounds per acre. Fertilization has increased the amount of grazing as much as three fold in some tests. Cultural treatments which tend to destroy or reduce the competition from the established sod are very beneficial and in some instances necessary to the establishment of clovers.

The analysis of clipped material shows a definite improvement of the quality of grazing as well as quantity following fertilization and introduction of clovers. The mineral content of the natural sod on these sandy soils is usually below the recognized minimum requirement for grazing animals. Following fertilization this content is increased above the minimum and with heavy fertilization approaches the optimum content.

Some Factors Affecting Pasture Production in Western North Carolina.—W. W. WOODHOUSE, JR., *North Carolina Agricultural Experiment Station, Raleigh, N. C.*

FERTILIZATION is essential in producing permanent pastures in western North Carolina. The effect of fertilizer upon yield and botanical composition of several sods has been studied since 1939. Lime has been found to be the first limiting factor with phosphate a close second. Potash applications are usually needed. The advantages of nitrogen use have not been clear cut.

Nitrogen applied to new seedings has resulted in slight increases in stands of grasses but has reduced legume stands. When applied to established stands, nitrogen has increased spring growth but has reduced summer and fall growth and has reduced legume stands. Total yield for the season has not been affected materially.

Lespedeza and white clover have been the two principal legumes present in these sods. They apparently differ in their ability to tolerate small applications of nitrogen. Lespedeza, when growing with grasses, is severely handicapped by nitrogen application even on soils that are very poor. White clover seems to be more able to compete with the grasses under these conditions. Close grazing is essential to enable either of these legumes to compete with grasses under nitrogen applications.

Some Experiences in Revegetating Poor Hill Land Pastures in West Virginia.—R. M. SMITH, G. G. POHLMAN, F. W. SCHALLER, AND D. R. BROWNING, *University of West Virginia, Morgantown, W. Va.*

ON the Agronomy Farm at Morgantown, W. Va., and on a number of widely scattered poor hill land pastures throughout the state, comparisons have been made between standard surface treatment and tillage plus reseeding in addition to treatment. Tillage and management practices have been followed which could be carried out on the farm where each trial was conducted. Twelve trials have involved plowing as well as shallow tillage. Various other trials have been made with shallow tillage alone.

Satisfactory stands of various legumes and grasses have been obtained both by plowing and by shallow tillage, quickly improving the quality and palatability of the herbage. An advantage over surface treatment, measured by clipping yields and species estimates, extends through the second year under various grazing conditions. The practicability of reseeding is dependent upon a number of factors, including the natural vegetation, the soil, the tillage tools available, the pasture management, and the need for quick pasture improvement. Shallow tillage is easier when the ground is moist or wet in the very early spring but has proved successful in the early fall. Erosion hazards from overgrazing are much less on shallow tilled than on plowed ground.

The most promising species for pasture seeding include Louisiana white clover, alsike clover, sweet clover, orchard grass, ryegrass, Kentucky bluegrass, and redtop. Under close grazing the herbage is mainly white clover, orchard grass, and Kentucky bluegrass after the second year.

MISCELLANEOUS PAPERS

Critical Phosphorus and Potassium Levels in Ladino Clover Plants.—ALBERT ULRICH, *University of California, Berkeley, Calif.*

LADINO clover, containing about 600 p.p.m. or less of phosphorus as phosphate extracted by 2% acetic acid from dry petioles (leaf stalks), was deficient in phosphorus as indicated by responses to phosphorus fertilization in pot tests. In the same series of experiments conducted over a 2-year period, clover with about 0.8% or less of total potassium may be considered deficient in potassium.

Grass-Legume Hay Response to Various Fertilizer Ratios.—AVERY RICH AND BASIL E. GILBERT, *Rhode Island State College, Kingston, R. I.*

A SERIES of plots known as the potash experiment has been used since 1911 to determine the requirements of various crops to varying amounts of potash. Other plots have been added more recently to determine the amounts of nitrogen and phosphoric acid required by various crops.

A crop of grass-legume hay was seeded with oats as a nurse crop in the spring of 1941 on all plots in the test. A mixture of 7 pounds alfalfa, 5 pounds red clover, 3 pounds alsike clover, 3 pounds timothy, and 2 pounds red top was used. There was a good stand the first year on all plots.

The standard fertilizer application was 20 pounds N, 80 pounds P_2O_5, and 100 pounds K_2O per acre each year. Reduced amounts of N or P_2O_5 did not reduce the legume stand or the total yield of hay.

When potash was reduced from 100 pounds to 50 pounds, there were very few legume plants present after the first year, and the total yield was greatly reduced. When the potash was reduced to 25 pounds, almost no legumes were present in the stand, and the reduction in yield was even greater.

Pasture Renovation Experiments in Rhode Island.—IRENE H. STUCKEY, *Rhode Island State College, Kingston, R. I.*

THE results from 3 years of pasture renovation experiments have given valuable information in regard to the establishment and maintenance of desirable pasture plants.

Agronomy, A Phase of Military Engineering.—LT. COL. R. H. MORRISH, *Chief of Engineers, U. S. Army.*

AS A result of the excavation, filling, and grading incident to new construction at military installations, most of the existing vegetative cover was destroyed and much of the top-soil removed or buried beneath fills. This destruction of ground cover brought about serious dust and erosion control problems at all types of military installations, particularly on aircraft landing fields, in cantonment areas, and at station and general hospitals. The re-establishment of vegetation on such areas became the responsibility of the Corps of Engineers. Agricultural experience had indicated that the re-establishment of "heavy duty" vegetation under such unfavorable conditions was extremely difficult, and that revegetation by natural processes was too slow. Some of this work was accomplished as a part of new construction; however, the major portion of it has been and is being done by post engineers as a part of grounds maintenance operations.

The re-establishment and maintenance of vegetative cover on military installations has been justified strictly on a utilitarian basis. The need for such work, to protect the investments of the War Department in equipment and structures, to facilitate training operations, and to protect the health of military personnel, is obvious. In accordance with War Department Directives no revegetative work has been or is being done to provide for landscaping and beautification.

In planning for and in the early accomplishment of revegetative, dust and erosion control work, technical assistance was obtained from the U. S. Dept. of Agriculture and from the state agricultural experiment stations. Soon after the initiation of the work, experienced agronomists were employed on the staffs of service command engi-

neers and grounds maintenance supervisors were placed on the staffs of post engineers. The responsibility for the accomplishment of revegetation, dust, and erosion control was delegated to these individuals and as a result such work has been and is being accomplished in a timely and economical manner. Vegetation has been recognized as an important construction material and its proper management has become an integral part of maintenance operations at all military installations. Agronomy is now recognized as a phase of military engineering and experienced agronomists are qualified as dust and erosion control engineers. The work as accomplished has been similar to agriculture in that the same methods, materials, plant species, fertilizers, and equipment have been used; however, the similarity ceases with the establishment of the cover since the production of pasture, hay, grain, or forage on Army installations does not become a part of the military objective of posts, camps, stations, or airfields.

The maintenance work involved includes fertilization, mowing, renovation, reseeding, weed and insect control, the spraying and pruning of existing trees and shrubbery, and the maintenance of adequate surface water disposal systems. These operations are being done in a manner which has resulted in tremendous savings to the War Department by reducing maintenance costs and by providing adequate protection to buildings, roads, runways, equipment, and military personnel.

Yields From Single-Plant Hills vs. Multiple-Plant Hills At The Same Population of Corn Plants Per Acre.—GEORGE H. DUNGAN, *University of Illinois, Urbana, Ill.*

IN 1930 a study of the performance of corn plants grown singly but in closely spaced checked hills was begun by the Illinois Experiment Station to discover if this method of planting had any advantage over the usual method of hill planting. These tests have been continued through seven seasons.

Results show that in five of the seven years corn in single-plant hills exceeded that in multiple-plant hills in grain yield per acre. In two of the five years, namely, in 1932 and 1942, when moisture supply was plentiful and well distributed, single-plant hills exceeded multiple-plant hills an average of 9.4 bushels an acre. The average of all seven years' results shows the single-plant hills to be superior by 3.1 bushels. Stover yields were uniformly greater for the individually spaced plants as were also the number of tillers and diameters of stalks.

Alfalfa and Grass Percentage Determinations with the Inclined Point Quadrat Apparatus at Different Stages of Development of the Mixtures.—A. C. ARNY, *University of Minnesota, St. Paul, Minn.*

TO OBTAIN information on the relative percentage composition of alfalfa-grass mixtures at successive stages of development, readings were made in June 1942 at average heights of 4, 8, and 12 inches. Six mixtures of alfalfa, *Medicago media*, and grasses growing on

duplicate plots were used. The grasses were brome grass, *Bromus inermis*, two strains; timothy, *Phleum pratense;* crested wheat grass, *Agropyron cristatum;* Kentucky bluegrass, *Poa pratensis;* and Canada bluegrass, *Poa compressa.* At each stage of development six readings were made on each plot and all hits, including bare ground for the last one where no vegetation was present, were recorded. As soon as each reading was completed the vegetation on an area 10 × 19 inches through which the needles had passed was harvested. Hand separations were made, dry weights of each component made, and percentages determined.

Average number of hits per quadrat needle were lower for alfalfa than for the grasses, as shown in Table 1. The number of hits per needle did not vary greatly for the readings taken at the different heights. The dry weights in grams per hit were greater for alfalfa than for the grasses at each height and the weights per hit increased greatly as the height of the growth increased.

TABLE 1.—*Number of hits per needle and dry weights per needle hit for alfalfa and grasses in the mixtures as determined at three heights.*

	Av. height 5.5 in.		Av. height 8.5 in.		Av. height 11.1 in.	
	Alfalfa	Grass	Alfalfa	Grass	Alfalfa	Grass
Number of hits per needle...	9	23	13	20	12	20
Dry weight per needle hit...	0.77	0.27	1.30	0.42	1.54	0.69

Average alfalfa and grass percentages determined from inclined quadrat hits and from dry weights at the three heights are given in Table 2.

TABLE 2.—*Percentage composition of six mixtures as determined from original point quadrat readings, dry weights from hand separations of the vegetation through which the quadrat needles passed and from corrected quadrat readings.*

Source of data for determinations	Av. height 5.5 in.		Av. height 8.5 in.		Av. height 11.1 in.	
	Alfalfa	Grass	Alfalfa	Grass	Alfalfa	Grass
Original quadrat readings...	29.4	70.6	38.7	61.3	38.6	61.4
Dry weights..............	52.5	47.5	64.6	35.4	58.3	41.7
Corrected quadrat readings..	52.8	47.2	62.1	37.9	59.1	40.9

At the three average heights at which determinations were made, the percentages of alfalfa as determined from the original quadrat readings were 23.1, 25.9, and 19.7 too low and the grass percentages correspondingly too high in comparison with the percentages determined from dry weights of hand-separated samples.

Corrections were made to take care of the lower dry weights in grams per needle hit from the quadrat readings[1] for the grasses as

[1]For method used in making corrections see this JOURNAL, Vol. 34, pages 238–247.

compared with the alfalfa and the differences in dry weight per hit for the different grasses. The average corrected percentages as given in Table 2 are similar to those derived from the dry weights.

These data present additional evidence for applying correction factors to inclined quadrat readings made on alfalfa-grass mixtures when percentage compositions which approach closely those obtained from dry weights of the components separated by hand are desired. The correction factors varied with the heights of the mixtures at the time the readings were made.

One of the objects of making the percentage determinations of the mixtures at different heights was to learn how applicable these would be to the same mixtures harvested or grazed off at somewhat earlier or later stages of development. The results show a considerable change in the average percentage of alfalfa in the mixtures at the three stages of development.

The Development of a Synthetic Variety of Corn from Inbred Lines.—
H. K. HAYES, E. H. RINKE, and Y. S. TSIANG, *University of Minnesota, St. Paul, Minn.*

ALL possible single crosses were studied between 20 inbred lines and 8 lines were selected, representing rather wide genetic diversity, that gave a relatively satisfactory performance in all single cross combinations with each other. Seventy-five seeds of each of the 28 single crosses between the 8 inbreds were mixed together and planted in an isolated plot in 1941. Several bushels of seed were harvested without making selection for ear or plant type. In subsequent years the variety has been increased in an isolated plot of about half an acre by selecting desirable plants, in hills with a good stand, surrounded on all sides by corn. About 100 ears were saved each year without making close selection for ear type, and after drying and processing, the seed was bulked and used in planting the following year's seed plot and yield trials.

The yielding ability and moisture content at husking of the inbreds were determined in randomized block trials at the Waseca branch station. Twelve hill plots, with three replications each year, were grown from 1941 to 1943, inclusive. Three rows plot of Minhybrid 403 were included, the central row of each plot being used in the comparisons. The yield in these trials was computed on a perfect stand basis.

Performance data for the single crosses were obtained from trials made in 1940 and 1941, at each of four locations in southern Minnesota. Minhybrid 403 and open-pollinated Murdock were included also. Randomized block trials in 12-hill plots with three replications at each location were used. These tests were made by planting five kernels per hill and thinning to a stand of three per hill. Only perfect stand hills surrounded on four sides by corn were used in the comparisons.

The synthetic variety was compared with Minhybrid 403 and Murdock from 1942–44, inclusive, in the Southern Zone. These trials were made in randomized blocks, in 18 hill plots with three

replications at each location. The trials were carried out at three locations in 1942, two in 1943, and three in 1944. In 1944, trials were conducted also at two locations in the South Central Zone where Minn. No. 13 was used instead of Murdock. Three kernels were planted per hill in 1942 and four per hill in 1943–44. No corrections were made for differences in stand except in 1944 when the yields were computed on the basis of number of hills harvested per plot that had a stand of one or more plants per hill.

The average yield of the eight inbreds in bushels per acre was 30.9 with a moisture content of 32% at husking, compared with a yield of 68.8 bushels for Minhybrid 403 and moisture percentage of 24.4. The average percentage yield of the inbreds in terms of Minhybrid 403 as 100 was 44.9.

The average yield of the 28 single crosses was 73.4 bushels with a moisture content of 23.5% compared with Minhybrid 403 with a yield of 66.6 bushels and moisture content at husking of 23.6%. The lowest yield per acre of any one of the single crosses and the moisture content at husking were 65.2 bushels and 21.6%, respectively, while the highest average yield obtained for any single cross was 82.9 bushels with a moisture content of 24.6%. With Minhybrid 403 as 100 the average comparative yielding ability of the 28 single crosses was 110.2 and for moisture content 99.6%.

The predicted percentage yielding ability of the synthetic variety in terms of Minhybrid 403 as 100 was calculated by the following formula: Yield of synthetic variety = average yield of inbreds (44.9%) + ⅞ [average yield of 28 single crosses (110.2%) – average of 8 inbreds (44.9%)] = 102.0%. On this basis the synthetic variety may be expected to yield about as well as Minhybrid 403.

The average yield in bushels per acre, moisture content at husking, and percentage stand for 1942 to 1944, inclusive, are given in Table 1 for the synthetic variety, Minhybrid 403, and for the open-pollinated variety. The latter was obtained by averaging the results obtained for Murdock in the Southern Zone and for Minn. No. 13 in the South Central zone.

TABLE 1.—*Performance of synthetic variety, Minhybrid 403, and open-pollinated varieties in trials at 10 locations, 1942–44, inclusive.*

Variety	Yield, bu.	Moisture, %	Stand, %
Synthetic	69.4	27.2	94
Minhybrid 403	66.8	24.9	94
Open-pollinated	55.6	25.9	79

When yield and percentage moisture of Minhybrid 403 were taken as 100, the calculated percentage values for synthetic were 103.9 and 109.2, respectively. If yield is rather directly correlated with moisture percentage at husking, then the synthetic variety is not quite equal to Minhybrid 403 in performance. In these trials both Minhybrid 403 and synthetic were greatly superior to the open-pollinated varieties. A large part of the differences in yield were due to stand differences, although both synthetic and Minhybrid 403

gave an average production of 1.03 good ears per plant while the open-pollinated variety averaged only 0.91 good ear per plant. The synthetic was about equal to Minhybrid 403 in resistance to root lodging and both were superior in this respect to the open-pollinated variety.

The results of these studies give further emphasis to the importance of studying combining ability of the selected material used in producing a synthetic variety. The genetic diversity of material used in the corn synthetic variety emphasizes the probable importance of combining strains of different genetic origin when such strains are adapted for use in the region where the improved variety will be grown.

Winter Injury and Persistence in Alfalfa.—FRED REUEL JONES, *University of Wisconsin, Madison, Wis.*

IN 1940 over 500 clons from unselected plants from four more or less wilt-resistant varieties of alfalfa were set in cultivated rows to determine how long such plants will live under favorable cultural conditions in the local environment. None of the four succeeding winters is judged to have been unusually severe. After the third winter most of the clons appeared to be in excellent condition, but many deteriorated during the following summer. After the fourth winter from 12 to 30% of the clons were dead, and about twice as many were in poor condition. The cause of poor condition and death appeared to be progressive deterioration following winter injury from which a few clons appear to have suffered little.

From observation among these clons and many others it appears that winter injury occurs in several characteristic ways uniformly in clons, and that clons respond differently to seemingly equal degrees of injury. Characteristic behavior becomes more apparent as the plants become larger and older. Thus, wilt-resistant clons observed for 5 years show great differences in ability to survive and thrive, with a small percentage showing marked superiority. From this it appears that selections based on actual field performance of clons in the region should result in a strain with increased ability to withstand the usual hazards of the climate.

FORAGE CROP IMPROVEMENT

Some Problems in Testing Selected Strains of Forage Plants in Pasture Trials.—H. L. AHLGREN, *University of Wisconsin, Madison, Wis.*

APPROXIMATELY 11,800 plants of Kentucky bluegrass, *Poa pratensis* L., representing 353 collections made in Wisconsin, 92 in other states, and 45 in foreign countries, were grown in space-planted rows in breeding nurseries at Madison, Wis., during the period 1936 to 1939, inclusive. Seventy-four of the better appearing progenies were selected as being of sufficient promise to warrant further evaluation and were grown in small plot pasture trials.

In results thus far superior types obtained from nursery selection have proved to be disappointing in producing increased yields of forage in pasture trials; differences between selected and commercial lots being small and of doubtful practical value. Further, when grown in small plots, there was a marked tendency for original differences between strains to become less pronounced as seedings increased in age. Additional investigations, under conditions in which moisture and particularly fertility are less limiting, are required before the practical value of different strains for use as pasturage can be ascertained more accurately.

There was little or no relation between estimated yields of the selections grown in space-planted nursery rows and in mass seedings. There was little or no relation between yields of the selections grown in mass seedings and disease reaction. While there was some indication that taller growing, more productive selections were better competitors with white clover than shorter growing less productive types, the correlations obtained when comparisons were made between yields and competitive ability with white clover were so low as to be of no value for purposes of prediction.

Results which were obtained indicate that growth and appearance of spaced plants of bluegrass cannot be used safely to predict the performance of the same progenies in mass seedings. It would appear that improved technics would be desirable in the initial phases of breeding programs involving the improvement of bluegrass.

A Selection Experiment with Kentucky Bluegrass.—H. K. HAYES AND H. L. THOMAS, *University of Minnesota, St. Paul, Minn.*

IN 1937, divots of Kentucky bluegrass were collected from 150 old pastures and waste places throughout Minnesota, the material being collected from a wide range of soil and other environmental conditions. These divots were broken down to individual plants. Two hundred and eighty-one vigorous plants with different growth habits were selected and increased as clones.

From 30 of these clones seed was saved under a bag and from unprotected panicles of the same clonal plants. The sexual progeny were grown in paired comparisons. There was close agreement between the two types of progenies for each of the 30 clones.

The 281 clones, plus 3 selected from a variety introduced from Svalof and 2 from Ottawa, were placed in a randomized block test, in groups of 23 clones per block, with two replications. Each block contained one selection made up of the clonal increase of 11 plants from one pasture type to serve as a check. The clones were increased by planting clonal pieces 7 inches apart each way in rectangular beds consisting of 7 by 11 pieces. These were planted in the fall of 1939. The beds were sufficiently well established so that they were cut throughout the two seasons of 1941 and 1942 when the grass reached an average height of about 4 inches.

Average yields for 1941 and 1942 for this test were placed in classes with class centers differing by the least significant difference at the 5% point, the central class being the average of the trial. The check

yielded somewhat more than the average of the clones. There was good agreement in yield between 1941 and 1942. Distribution of clones that gave relatively good stands in both 1941 and 1942 is shown in Table 1.

TABLE 1.—*Classes differing by least significant difference at 5% point.*

Classes	−2	−1	0	+1	+2
Number of clones	2	63	118	65	6

It is apparent that the different clones showed wide differences in yielding ability. Forty-eight were selected for further testing in plots to be established from open-pollinated seed. Selections were based on total yield, yield in July, desirable appearance for lawn purposes, and for mildew resistance. A few lines were included that gave low yields, or were susceptible to mildew, or that were not of promising appearance as lawn types. Plots 8 × 8 feet with four randomized replicates of these sexual progeny were planted in the fall of 1943. White clover was added to the third and fourth replicates in the spring of 1944. Eight strains introduced from Wisconsin were included, making 56 in all.

Clippings were taken in 1944 whenever the grass reached a height of 3 or 4 inches, which occurred seven times throughout the growing season. The range in total yield per acre at the 14% moisture basis was from 3,046 to 4,904 pounds, the commercial check yielding 3,437 pounds. In total yield the commercial check ranked 42nd, there being five strains which were significantly better than the check at the 5% level of significance. For summer yield commercial ranked 48th, with nine strains significantly better than the check at the 5% level.

There was little or no relationship between total yield as clones in 1941 and 1942 and the yield of their seed progenies. The average yield of the seed progenies of five clones that yielded less than the check in 1941–42 on the 14% moisture basis was 3,973 pounds per acre, while the average yield in 1944 of the remaining 51 clones was 3,689 pounds.

Methods of Evaluation of Red Clover Strains Grown Alone and with Timothy in Small Plots.—J. H. TORRIE AND J. L. ALLISON, *Wisconsin Agricultural Experiment Station, Madison, Wis.*

STUDIES have been conducted at Madison, Wis., for several years to determine if the relative forage yields of red clover strains are the same in small block trials when seeded in rows or broadcast and with or without timothy. The interaction of strains × seeding methods for clover yield, excluding timothy, was not significant, indicating that relative yields of the clover strains were similar regardless of method of seeding. The interaction of strains and seeding methods for total yield of forage, clover + timothy, was significant in one year's trial only. In this trial there was a wide spread in the forage yield of the clover strains when seeded alone. When

seeded with timothy, the spread in total yield of forage was much less, indicating a greater proportion of timothy with the low-yielding clover strains. The total yield of forage produced by the four methods of seeding was considerably less for clover seeded in rows than for the other three methods, which in turn differed slightly from each other in total yield. Results from these trials indicate that clover strains seeded in small plots react the same for forage yield when planted in rows or broadcast and with or without timothy.

Evaluation of Strains of Kentucky Bluegrass in Association with White Clover.—W. M. MYERS AND V. G. SPRAGUE, *U. S. Regional Pasture Research Laboratory, State College, Pa.*

THIRTEEN selected strains and two commercial seed lots of Kentucky bluegrass were planted in replicated field plots in an experiment designed to measure relative yields of the strains when grown in association with white clover. Two clipping treatments were used, *viz.*, (1) until July 1, plots were clipped with lawn mower set at ½ inch when the plants averaged 3 to 4 inches in height, after July 1, plots clipped with the lawn mower set at 1 inch when plants averaged 4 to 5 inches; and (2) plots clipped throughout the summer with the lawn mower set at 1 inch when the plants attained an average height of 4 to 5 inches. Data on yield and botanical composition were collected at each clipping date for three years. Statistically significant differences among strains for yield of total herbage, yield of Kentucky bluegrass, and percentage of associated white clover were obtained at each clipping date in each year.

The interaction of strains × clipping treatment was not significant at any date. There was no noticeable tendency for the differences among strains to disappear in the third year as compared with the first. The short-leaved, dense sod forming, "pasture" type strains were consistently inferior to the commercial checks in yield, whereas two tall, long-leaved strains exceeded the checks in yield.

SOILS SECTION*

GENERAL PROGRAM

Soil Conditions and the Future of Great Plains Agriculture.—HORACE J. HARPER, *Oklahoma Agricultural Experiment Station, Stillwater, Okla.*

SOIL problems in the Great Plains Region will eventually become more numerous as a result of the continued production of soil-depleting crops. Although a majority of the immediate problems are physical in nature, a gradual decrease in the organic matter and nitrogen content of the soil will eventually require more attention than past experimental data would indicate is necessary to maintain crop yields. Since the organic matter content of the Great Plains soils

*Papers scheduled to be presented before the Soil Science Society at the postponed meeting of November, 1944, will be published in full in the PROCEEDINGS. Abstracts of most of the papers are included here.

decreases from north to south, a deficiency of organic matter would be expected to appear first in the southern part of the area. Organic matter and nitrogen also decline from east to west in the same latitude but limited rainfall in the western part of this region will greatly restrict soil-improving practices other than the use of grass to increase fertility and methods for soil and water conservation.

Experiments have shown that the loss of organic matter in soils planted continuously to row crops is more rapid than on similar land planted to wheat each year. Since a response from nitrogen fertilization applied to a sorghum crop is not obtained until the soil fertility level is lower than in soils which respond to nitrogen fertilization when winter wheat is planted on them, sorghum can continue to be grown on the land for many years without fertilization after wheat fails because of limited soil fertility. Stimulation of plant growth as a result of nitrogen fertilization often increases forage production but reduces grain yields. This would not be objectionable where livestock are used to stabilize farm income during periods when climatic conditions are not favorable for the production of cash crops.

Since water is a very important limiting factor in plant development in this area, the use of methods which will increase the absorption and optimum utilization of rain and the use of cropping systems which have been most effective in producing maximum yields will continue to be important factors in the successful management of a high percentage of the cultivated soils.

The need for water conserving practices will increase as the rate of infiltration of rain is decreased by a slow deterioration in the physical structure of the soil brought about by loss of soil organic matter and mechanical disintegration of soil aggregates. Contour planting and terracing to conserve water have been more effective in increasing crop production in the southern part of the Great Plains than trashy tillage which has also increased the weed problem in some areas. Grass rotations have been recommended to improve the physical structure of the soil and increase organic matter, but they have not materially increased crop yields.

Commercial fertilizer has increased wheat production when applied to soils in the northern part of the Great Plains because it stimulates early growth and as a result plant roots can obtain more of the available plant nutrients needed to produce high yields during the relatively short growing season which prevails.

In a few areas where irrigation is practiced both nitrogen and phosphorus soon become limiting factors in plant development.

Soil surveys have shown that a considerable acreage of land in this area should be planted to grass either because (1) the soil is too shallow for cultivation or (2) serious loss or damage is occurring as a result of water or wind erosion. Since the acre income from grass is normally lower than from similar land suitable for the production of row crops, planting large areas of land to grass will reduce farm income unless the size of the farm can be increased. Such a condition would require fewer farm families to operate the land.

The future demand for food willl determine to a very great extent whether more intensive soil-improving practices can be used to main-

tain crop yields in this area as the soil fertility declines below the climatic possibilities for crop production.

A Land Use Planning Program in Action.—W. D. LEE, *North Carolina Agricultural Experiment Station, Raleigh, N. C.*

THE French Broad River Basin in North Carolina is an agricultural-industrial area, subject to occasional floods which damage farm and factory. The control problem is that of water utilization, involving engineering and agricultural phases. Engineering procedure contemplates the use of structures; the agricultural process is concerned with land cover. Study of the problem was one of full cooperation between state and federal agencies. Several departments of TVA conducted engineering investigations, made woodland studies, and designed a series of detention reservoirs. The Appalachian Forest Experiment Station furnished essential data. Representatives of North Carolina College of Agriculture made the land cover inventory. This was a study of 100 unit test demonstration farms which had carried on a cooperative land use program for 6 years, and strip surveys which determined cover conditions over the basin. Based on improvements shown by the demonstration farms and on data presented by the several agencies, a group of representative farmers drew up a 20-year land use program.

The engineering report indicates that this program will lessen runoff considerably, will insure the safety factor of flood control structures, and will permit modifications in design. The College, aided by TVA, has placed extension agents in two segments of the Basin to aid farmers with their program.

SECTION I—SOIL PHYSICS

Aggregation Studies of Houston Clay in Mississippi.—RUSSELL WOODBURN, *Mississippi Agricultural Experiment Station, State College, Miss.*

HOUSTON clay, a dense structure prairie soil of Mississippi, is difficult to till when broken from sod, but extensive granulation or aggregation takes place by weathering after plowing. Investigation was made of the formation of aggregates by natural weathering, by laboratory wetting-drying cycles, and by freezing-thawing cycles.

It was found that aggregate size distribution in Houston clay was difficult to measure, the results varying widely depending upon pre-treatment of samples before wet sieving. Curves were drawn showing effect of repeated oven-drying-wetting cycles on amount of aggregates in each size class. Freezing-thawing cycles were also shown. Drying and wetting destroyed large aggregates and increased those from 210 to 20 microns in size. Somewhat similar results were found for Susquehanna clay, unlike Houston clay in pH and organic matter but similar in its montmorillonite base. Houston clay was found to re-aggregate well upon drying and wetting even after complete dispersal by mechanical means.

Houston clay subsoil, even after one drying and wetting, when brought to the surface, becomes far different in structure from its tight dispersed character in place. The results indicated that tillage practices, as affecting structure, can hardly be evaluated by water-stable aggregation. It was recommended that curves showing wetting-drying cycles plotted against aggregation for two soils might better compare the two soils than one single aggregate determination.

The Influence of Kaolinite and Montmorillonite on Aggregation.—J. B. Peterson, *Iowa State College, Ames, Iowa.*

DIFFERENCES in the morphology and water stability of aggregates produced from kaolinitic or montmorillonitic clays, alone or in mixtures, are definite and reproducible. Structure was induced by wetting and drying after complete puddling by working at the moisture equivalent. Montmorillonite produces a gelatinous mass which shrinks on drying into hard, globular lumps, connected by thin sheets with a tendency to curl and break, leaving angular edges. Such shapes are given the name "montmorillonitic structure". Pellets of pure kaolinite, on the other hand, do not break down into structural forms unless diluted slightly with montmorillonite or with sand, when they form distinctly parallel patterns of cleavage resulting in definitely platy structure.

Increasing dilutions with sand, calcium, iron, or montmorillonite inhibit the development of platiness in kaolinite. Iron and calcium produce granulation in both kaolinite and montmorillonite, the granulation increasing and the structural forms characteristic of the pure clays disappearing with increments of calcium or iron.

Montmorillonite resulted in greater water stability than did kaolinite as measured by wet sieving except where calcium was added. The higher rates of calcium increased the stability of the kaolinite mixtures and reduced that of the montmorillonitic ones, a complete reversal of the usual effect.

Some Slope and Water Relations Affecting Movement of Soil Particles: II. Field Studies.—Luke A. Forrest, *Soil Conservation Service,* and J. F. Lutz, *North Carolina Agricultural Experiment Station, Raleigh, N. C.*

THE results of a laboratory investigation on the effects of slope, quantity, depth, and velocity of water on the movement of soil particles were reported last year. During 1944 data have been obtained under field conditions from a series of row grade plots at the Soil Conservation Experiment Station near Raleigh, N. C. These plots are on Appling sandy loam soil. The grade varies from 0 to 30 inches per 100 feet with intervals of 6 inches.

Water velocity measurements were made on all plots when freshly plowed and again after a rain by applying water at a constant rate and timing the flow. Mechanical analyses have been made of the soil and of the eroded material from several individual rains and of a composite from all the eroded debris during the entire growing

season of a tobacco crop. The analyses show that the easily suspended material is lost in much greater amounts than it occurs in the soil, thus continuously increasing the sandiness of the soil. The ratio of fine particles (<0.02 mm) in the eroded material to those in the soil increased at first and then decreased as slope increased. The ratio of coarse particles in the eroded material to those in the soil decreased as slope increased up to 18 inches per 100 feet and then decreased. Except at the 0 and 30 inch grades, the ratios for the coarse material were less than unity. These variations in ratios, and in total soil loss with grade, agree with what would be expected in light of the laboratory data reported last year.

The Relation Between the Degree of Aggregation in Geary Silt Loam and Its Moisture Content at Sampling Time.—ERIC B. FOWLER AND J. C. HIDE, *Kansas State College, Manhattan, Kans.*

SAMPLES were taken from a series of plots at 11 times during 1943 and the degree of aggregation determined by wet sieving. The aggregate determinations were made without previous drying and within a few hours of the time the samples were taken from the field. A significant positive correlation was found between the degree of aggregation and the soil moisture content. Tillage treatments which influence the rate of drying of the soil also influence the degree of aggregation in the soil. The carbon and nitrogen content of the well-aggregated fraction was higher than in the poorly aggregated fraction, but the carbon-nitrogen ratio was similar in the two fractions. Samples taken adjacent to a dead furrow where subsoil was exposed were more highly aggregated and the degree of aggregation did not vary over as wide a range as on adjacent surface soils.

A Study of the Shrinking and Swelling Properties of Rendzina Soils.—J. R. JOHNSTON AND H. O. HILL, *Soil Conservation Service, Temple, Tex.*

THE most striking physical phenomena of the Rendzina soils in the blackland area of Texas are unusual swelling and shrinking which accompany wetting and drying. These physical properties are responsible for many of the difficulties encountered in farming these soils. The reduction in volume of soil accompanying the loss of a definite quantity of water was greatest near the midpoint of the soil moisture range. Study of the data obtained permits a better understanding of the formation of "dry weather" cracks in the Rendzina soils of Texas. Horizontal soil shrinkage is evidenced by vertical cracks. Vertical shrinkage is evidenced by change of surface elevations. In profile openings to expose vertical cracking it was found that soil moisture zones around the cracks formed a rather definite pattern. The moisture content 1 inch from the cracks was less than it was 3 inches away. This emphasizes the drying effect of these cracks on the soil. The vegetative cover influences the surface crack pattern. Under a solid vegetative cover or fallow the cracks develop irregularly and resemble mud cracks; whereas, under cotton or corn a

continuous crack forms in the row middle with other cracks bisecting it at right angles. Slaking of soil clods is caused by wetting and drying. After dry periods this action is necessary before a desirable seedbed can be prepared.

Moisture and Energy Conditions During Downward Entry of Water Into Moist and Layered Soils.—E. A. COLMAN AND G. B. BODMAN, *U. S. Forest Service, Glendora, Calif.*

SOIL moisture and pressure potential conditions were studied during the downward entry of water into laboratory-packed soil columns. Infiltration was studied at normal moisture capacities and in dry layered soils.

Compared with initially dry soils the moist soils showed slower water entry and faster wet front penetration, while indicating lower moisture contents in the infiltration zone. Explanations are offered by observed lower pressure potential gradients and higher prevailing permeabilities in moist soil, while the infiltration process is fundamentally identical to that in dry soil.

The infiltration characteristics of the layered column: silt loam over sandy loam were the same as those of a uniform column of silt loam, the rate of water supply to the sandy loam being limited by the lower permeability of the silt loam. With the layer sequence reversed the silt loam limited the rate of water entry into the sandy loam, resulting in the development of positive pressures in the latter. Again the silt loam behaved as it had in a uniform column. Under field conditions the latter sequence could cause lateral subsurface water flow if the silt loam infiltration rate were exceeded. The study has demonstrated the usefulness of energy considerations in interpreting the infiltration process.

Some Factors Affecting the Percolation of Water Through a Layer of Loessial Soil.—T. M. MCCALLA, *Soil Conservation Service, Lincoln, Nebr.*

THE percolation rate of the parent material of the Peorian loess when irrigated or sprinkled was low. The reverse was true for the topsoil of the loess when irrigated or protected with crop residues. Water percolated more rapidly through the topsoil than the subsoil of the Peorian loess under similar conditions of testing, although the difference when they were sprinkled in a bare condition was very slight. The greater amount of organic matter in the topsoil increased the size and stability of aggregates, but when the aggregates were broken down the presence of organic matter or other binding materials did not increase the percolation rate. The topsoils tested with different size lumps had a percolation rate under irrigation without sprinkling of 5 to 100 times greater than the loess subsoil samples.

The percolation rate can be varied to quite a considerable extent by changing the mechanical state of the soil. The soil should be left in a lumpy condition for increasing water intake. Soil finely pulverized and with no lumps has a low percolation rate regardless of whether it has organic matter.

SECTION II—SOIL CHEMISTRY

Boron Availability in Soils as Influenced by Organic Matter and Soil Reaction.—K. S. Berger and R. J. Laird, *College of Agriculture, Madison, Wis.*

THE content of available boron and organic matter and the pH were determined on 171 soil samples representing 73 soils and 23 soil types. The samples represented the 0–6, 6–12, and 12–24 inch layers of virgin and cultivated soils.

A positive correlation was found to exist between the available boron and percentage of organic matter in all layers of the virgin soil and in the surface and deep layers of the cultivated soil. A positive correlation was also found to exist between the available boron content and pH in all three layers of the virgin soils. In the cultivated soils, however, there was no significant correlation. The investigation was essentially limited to soils with a neutral or acid reaction.

The data indicate that the positive correlation of amount of available boron to amount of organic matter is due to the ability of certain organic compounds to hold boron in a form readily available to plants.

Availability to Plants of Exchangeable and Acid Soluble Soil Potash.—O. J. Attoe and E. Truog, *College of Agriculture, Madison, Wis.*

AS regards the forms of potash in soils, it now appears that besides the exchangeable or readily available and the feldspar and mica or difficultly available forms, appreciable amounts of a form of intermediate availability are often present. This potash of intermediate availability probably has its origin in the fixation or change of exchangeable potassium to a nonexchangeable or fixed form, which however, may still be extracted with a dilute acid.

In field experiments where heavy potash applications had been made it was found that, after 18 months, a considerable portion of the applied potash had become nonexchangeable but could be extracted with one-half normal hydrochloric acid. Also in pot tests, corn and oats were able to make considerable growth on soils after all exchangeable potash had been removed by leaching with a suitable salt solution.

In soils under natural conditions, an equilibrium exists between the exchangeable and fixed forms so that a change from one to the other takes place to some extent, depending upon the supplies of each.

Crop Requirements vs. Soil Requirements in Plant Growth.—Robert H. Bray, *University of Illinois, Urbana. Ill.*

THE relation between the crop requirement and the soil requirement of a crop for a soil nutrient is not a direct relationship. It does not follow for example that a crop which takes up 50 pounds per acre of potassium has a higher soil requirement for potassium than a different species which takes up only 35 pounds. This fact can now be illustrated by using the crop requirement values for corn, oats, wheat, soybeans, and clovers established by the writer in

previous work. For example, wheat has a higher soil requirement for phosphorus and, on deficient soils, a higher fertilizer requirement than corn, yet it takes up less phosphorus than corn under similar conditions. Crop composition and crop removals are, therefore, not a guide to fertilizer needs or fertilizer ratios. This is particularly true of the adsorbed soil nutrients such as phosphorus and potassium and is less true of the unadsorbed nutrients such as nitrate.

Phosphate Fixation by Soil Minerals, III.—A. T. PERKINS AND H. H. KING, *Kansas State College, Manhattan, Kans.*

PREVIOUS data have shown great differences in the ability of various soil minerals to fix phosphate. These previous studies have dealt with minerals of several families and types ground to pass a 100-mesh sieve, i.e., with minerals smaller than 150 microns in diameter. The present paper expands this data correlating phosphate fixation with particle size of the minerals. The minerals ground to pass a 100-mesh sieve have been separated by sedimentation. The particle sizes obtained are in the range of 150, 75, 15, and 1 microns in diameter. Phosphate fixation has been measured for these mineral separates and found to increase with surface area. The increase of phosphate fixation plotted against decreasing particle size varies with the mineral and is related to type of mineral, its density, space lattice, and other factors. In most cases there is a break in the phosphate fixation curve as the particle size passes through the 1–10 micron size. Phosphate fixation increasing very rapidly at this point.

A Study of Sodium, Calcium, and Magnesium Ratios in the Exchange Complex.—J. S. JOFFE AND MIRYAM ZIMMERMAN, *New Jersey Agricultural Experiment Station, New Brunswick, N. J.*

THE Ca:Mg:Na ratios in solonetz and solonetzic soils are tabulated in this brief review of the subject. The methods used in introducing mixtures of cations in the exchange complex are discussed, with special reference to Ca:Mg:Na ratios. Data are given on the swelling, moisture absorption, and dispersion of soils containing various percentages of Na, from 5 to 50, in the exchange complex carrying various Ca:Mg ratios.

Sudan grass was grown in pot experiments on soil-sand mixtures. These were made up of six series of Ca:Mg:Na ratios. The results show the injurious effects of a Na content above 10% of the exchangeable cations, even with a high Ca:Mg ratio. A low Ca:Mg ratio behaved like a high Na content. Limits are indicated on the Ca necessary in Ca:Mg ratios to ameliorate the solonetz effects either of Na or of Mg.

The Use of Nitroso-R-Salt in the Determination of Exchangeable Potassium in Soils.—J. FIELDING REED, A. MEHLICH, AND J. R. PILAND, *North Carolina Agricultural Experiment Station, Raleigh, N. C.*

THE determination of exchangeable potassium in soils by a method which involves the use of Nitroso-R-Salt is described. Procedures are described for determination of potassium after extraction by N

NH_4Ac, 0.05N HCl, and 0.2N $BaCl_2$ buffered with triethanolamine at pH 8.1.

Solutions of these extractants were made up so as to contain known concentrations of potassium. After certain preliminary treatments, potassium was precipitated as potassium sodium cobaltinitrite. The following methods of determination were then used: (a) Titration with permanganate, (b) turbidimetric estimation, and (c) colorimetric determination by means of Nitroso-R-Salt. The Nitroso-R-Salt method was accurate and precise in all of the extractants employed. The volumetric potassium permanganate method was accurate with solutions containing more than 20 p.p.m. of K. With the Nitroso-R-Salt, however, accurate estimation was possible with solutions containing as little as 4 p.p.m. of K.

The applicability of this method to soils was then tried, using the three extracting solutions. Soils varying widely in texture, organic matter, and base exchange properties were selected for purposes of comparison. Data are presented illustrating the suitability of the Nitroso-R-Salt for determination of potassium extracted by the above-mentioned solutions. Information on the response of various crops to application of potash to these soils is presented. This permits a study of the relationship between response and amount of potassium extracted by these various solutions.

The Effect of Chlorine in Soils on its Distribution in the Potato Tuber.—J. M. MacGregor and C. O. Rost, *University of Minnesota, St. Paul, Minn.*

THE water-soluble chlorine content of Minnesota soils was determined. The amounts found were appreciably lower than reportedly present in soils of some other regions. The total chlorine content of field grown potato tubers on unfertilized soil and also of tubers grown on soils to which superphosphate and muriate of potash had been applied was studied. The amount of chlorine present in the unfertilized tubers was generally somewhat lower than that reported from other regions. Tubers grown in soils fertilized with muriate of potash at the rate of 200 pounds per acre showed increased amounts of chlorine, but the increase was not proportional to the additional quantities of soluble chlorine present in the soil during potato development. A study of radial chlorine distribution consistently showed higher concentrations of chlorine present in the skin and outer portions of the tubers. Radial chlorine distribution was apparently independent of soluble chlorine concentrations in both the tuber and in the soil in which it was grown. Longitudinal distribution of chlorine in tubers was affected by soluble chlorine concentrations in the soil. Soils low in this element produced tubers in which the chlorine was more or less evenly distributed from end to end of the tubers, usually being slightly higher in the seed end. Tubers grown in soils receiving muriate of potash tended to accumulate larger concentrations of chlorine in the stem end of the tuber, even after 3 months of storage. This unequal distribution is attributed to a "packing effect" on the part of the potato plant and shows that little or no diffusion of chlorine apparently occurs in the stored tubers.

The Determination of Some of the Thermal Characteristics of Clay Minerals and Soil Clays.—CHARLES D. JEFFRIES, *Pennsylvania State College, State College, Pa.*

THE method of differential thermal analysis of clay minerals consists of determining the difference in the heating rate over a range of 25° to 1,000° C between the clay mineral in question and a standard. The clay mineral and standard are heated together in a furnace so controlled that the temperature increases at a rate of approximately 10°C per minute. By means of thermocouples the temperatures of the standard and clay are measured and the endothermic and exothermic reactions of the clay observed.

In the course of this study it has been found that in order to obtain data which are comparable and capable of quantitative interpretations, the following conditions must be taken into consideration: (1) The samples and standard must be dried at a uniform temperature, and (2) the specific heats of the clays and standard must be known and samples upon which thermal data are to be determined must be weighed out in amounts equivalent to their thermal capacities.

The specific heats of clay mineral have been found to vary widely and there are included in this paper the results of the determination of the specific heats of ten typical clay minerals and 4 soil clays as well as their corresponding differential thermal curves.

Variance in the Carbonatation of Certain Calcium Silicate Materials in Soils.—W. H. MACINTIRE, S. H. WINTERBERG, AND H. W. DUNHAM, *Tennessee Agricultural Experiment Station, Knoxville, Tenn.*

AT heavy rates, unground quenched slag from phosphate reduction furnaces induced splendid response in pot cultures. Corresponding incorporations of 100-mesh slag proved deleterious, whereas those of wollastonite proved beneficial. Since both materials undergo dissolution readily in carbonated water suspensions, it had been assumed that they would behave alike in soils. Their opposite effects upon plant response prompted a study of their carbonatation in the soil.

Conversion of $CaSiO_3$ to $CaCO_3$ and concomitant pH changes in fallow and cropped soils were determined for full-depth incorporations of (1) *the slag*, quenched and unquenched; (2) *wollastonite*, raw, calcined, fused and air-cooled, and fused and quenched; and (3) experimental quenched limestone-quartz slags, one of which contained CaF_2. Unquenched slag proved less reactant than the quenched material, which underwent rapid conversion to $CaCO_3$. In contrast, wollastonite and its 800° and 1,100° calcines imparted virtually no increase in soil carbonates. Air-cooled fusions of wollastonite were reactant with CO_2; quenched fusions were more so. Influxed calcium fluoride accelerated carbonatation. In general, rise in soil pH was induced by wollastonite, limestone, and slag, in that order. Although all types of calcium metasilicate undergo ready conversion to $CaCO_3$ when suspended in carbonated water, they behave differently when incorporated with soils.

Potash Fixation by a Kaolinitic and a Montmorillonitic Soil.—C. Dale Hoover, *Mississippi Agricultural Experiment Station, State College, Miss.*

VARYING applications of K from KCl and K_2HPO_4 were made to two soils whose clay mineral fractions were known to be predominately kaolinite and montmorillonite, respectively. Potash was applied to the kaolinitic soil at rates of 10, 20, 40, and 400 p.p.m. K, respectively, and to the montmorillonitic soil at rates of 54, 108, 216, and 2,160 p.p.m. K, respectively. The exchange capacity of the latter was 36 M.E. per 100 grams of soil and 3.7 for the kaolinitic soil. The soils were stored moist and sampled after 1-, 3-, 6-, 9-, and 24-month periods, respectively, to determine H_2O-soluble, replaceable, and acid-soluble (1 N HNO_3, 90° C for 30 minutes) K. Potash not H_2O soluble or replaceable was considered fixed.

Both soils fixed considerable quantities of K from the highest applications. Where fixation occurred, more K was fixed from KCl than from K_2HPO_4, except for the 2,160 p.p.m. K application to the montmorillonitic soil. In this case, 75% of the K applied from both sources was fixed. Increasing applications of K to montmorillonitic soil resulted in increased fixation, but no K was fixed by the kaolinitic soil except from the highest rate of application (400 p.p.m K). From this application one half of the K applied as KCl was fixed, while one third of the K from K_2HPO_4 was fixed. Both soils fixed approximately as much potash in 1 month as they fixed over longer periods of time.

The Mechanism of Phosphate Fixation by Montmorillonitic and Kaolinitic Clays.—Russell Coleman, *Mississippi Agricultural Experiment Station, State College, Miss.*

PHOSPHATE fixation studies were made with kaolinitic and montmorillonitic fine clays (0.2μ) both before and after the free iron and aluminum oxides were removed from the clay minerals. The effect of time and pH upon the amount of phosphate fixed by the clays was determined, and the pH changes which occurred in the clay-phosphate system with phosphate fixation were measured.

Within the pH range of most soil (pH 5–7) montmorillonitic and kaolinitic clays fix almost as much phosphate in 24 hours as in 1 month, but in the more acid reactions (below pH 5), both clays fix considerably more phosphate in one month than in 24 hours.

Montmorillonitic and kaolinitic clays are able to fix small amounts of phosphate even after the free iron and aluminum oxides are removed, but the results strongly suggest that this fixation is not due to the clay minerals themselves but rather to free iron and aluminum which were not completely removed.

The results show that a considerable amount of the phosphate fixed by both clays, especially the large amounts fixed in the more acid reactions, is due to the replacement of hydroxide ions from the free iron and aluminum by the phosphate ions in solution.

SECTION III—SOIL MICROBIOLOGY

Inoculation Studies with Lyophiled Legume Bacteria.— M. D. APPLEMAN AND O. H. SEARS, *University of Illinois, Urbana, Ill.*

CULTURES of *Rhizobium leguminosarum* preserved in sealed glass tubes after freezing and vacuum drying (lyophiling) were maintained at room temperature for 3 years. The tubes were then opened and the dried cultures used for inoculating seeds of several legumes. Because the amount of culture in each tube was small, talc was used as a carrier. Although talc was superior to $Al(OH)_3$ and $CaCO_3$, it is possible that a better carrier may be found. After inoculation, one portion of the legume seed was planted immediately. Other portions were planted at intervals ranging from 1 hour to 19 weeks.

The presence or absence of nodules on the legume plants indicated that the species of nodule bacteria differed in their ability to survive when placed on legume seed and stored at room temperature. Red clover produced good nodulation for only 6 weeks with certain cultures, whereas alfalfa and lespedeza cultures remained viable for longer periods.

Although the results do not prove conclusively that lyophiled cultures can be used as a source of inoculation material, they do indicate their possibilities.

The Nodulating Performance of Three Species of Legumes.—J. K. WILSON, *Cornell University, Ithaca, N. Y.*

THE unusual ability of *Amorpha fruticosa* L., *Crotalaria sagittalis* L., and *Wistaria frutescens* Rafin to bear nodules after exposure to various isolates from many legumes provides evidence worthy of recording. Each species was exposed to 168 isolates and the occurrence of nodules taken as the criterion of the performance of each species. The isolates were from 49 genera and 104 species. In the order given above each symbiosed with 108, 120, and 135 of the isolates. The isolates represented most of the projected cross-inoculation groups of the legumes. It appears certain that most of the groups, if not all of them, would never have been proposed if tests for the power of the isolate to effect nodulation had been made employing one or more of these species before the groups were projected. Such data cut across efforts to assign species names to isolates from certain plants and emphasize that nodulation or no nodulation will depend on the particular isolate that is employed.

The Nature of the Flora on Field-retting Hemp.—W. H. FULLER AND A. G. NORMAN, *Iowa State College, Ames, Iowa.*

RETTING of hemp in the field involves the freeing of the fiber bundles from the surrounding softer tissues by the enzymatic action of microorganisms. Microscopic examinations of strips of hemp bark showed an abundance of fungi mycelium growing over and through the surface. Species of *Alternaria*, *Hormodendrum*, *Fusarium*, *Cephalosporium*, and *Phoma* were most abundant on all

hemp. *Fusarium* appeared more often on green hemp just beginning to ret and on hemp in the bottom of the swath. Generally, *Fusarium* appeared less frequently as retting progressed, while *Phoma* appeared more frequently.

The number of bacteria found per square centimeter of surface on retted hemp was 10 to 50 times greater than the number found on green unretted hemp.

Loss of Nitrogen from Flooded Soil as Affected by Changes in Temperature and Reaction.—W. H. WILLIS AND M. B. STURGIS, *Louisiana State University, Baton Rouge, La.*

LABORATORY and greenhouse experiments have been made on soil from the rice area of Louisiana at temperatures varying from 80° to 110° F and at reactions varying from pH 5.4 to 8.4. No losses of nitrogen as ammonia were observed at temperatures below 85° F when the soil was kept at optimum moisture. At temperatures above 85°F losses of very small quantities of ammonia nitrogen occurred, especially in the alkaline range. When the soil was flooded, the reaction of the soil became alkaline and ammonia was lost from the soil through the flood water over the entire temperature range during a period of 23 weeks. The ammonia losses observed varied from 13 to 22 p.p.m. In studies on virgin soil high in organic matter losses of from 25 to 325 p.p.m. of ammonia nitrogen were observed. Large losses occurred at optimum moisture at reactions above pH 8.0. In a study of the accumulation of ammonium nitrogen in the flood water, it was found that there were no accumulations above 3 p.p.m. at a temperature of 110° F. To determine more precisely the pH below which ammonium nitrogen could accumulate in flood water, a series of pots were set up containing a known amount of ammonium nitrogen in the flood water which was buffered at reactions varying from pH 5.4 to 8.4. The critical reaction below which ammonium nitrogen cannot accumulate in the flood water at a temperature of 110° F was found to be approximately pH 6.7. Nitrogen added as ammonium sulfate to the flood water at 110° F could not be recovered from the soil and algal growth in the water and soil.

SECTION IV—SOIL FERTILITY

Fertilizer Application Rationalized.—EMIL TRUOG, *University of Wisconsin, Madison, Wis.*

IT IS now possible to determine quite satisfactorily by chemical analysis the amounts or levels of available phosphorus and potassium in soils. Also, the desired levels of these nutrients for good crop production are now known; and the rates of application needed to produce these desired levels can be determined fairly well. This being the case, may it not be more rational in many cases, particularly in general farming, to apply phosphate and potash fertilizers in heavy infrequent doses so as quickly to attain and thereafter maintain these levels, than to apply small annual doses to each crop in the rotation?

A heavy dose of fertilizer, properly applied, makes it possible to produce the desired fertility in all of the soil of the furrow slice. This is highly desirable. The results of extensive field experiments relating directly to the subject are presented.

Comparative Effects of Plowing and Other Methods of Seedbed Preparation on Nutrient Element Deficiencies in Corn.—C. A. Bower, G. M. Browning, and R. A. Norton, *Iowa State College, Ames, Iowa.*

FOUR tillage treatments, plowing, discing, listing, and subsurface tillage, were compared as methods of seedbed preparation for corn on several important Iowa soil types. The growth of corn on disced, listed, and subsurface tilled soil was poorer than on plowed soil, the poorest growth being obtained with subsurface tillage. In experiments located on Clarion, Webster, and Fayette soils, the corn plants on unplowed soil showed marked potassium-deficiency symptoms, whereas those on plowed soil showed slight or no potassium-deficiency symptoms. Chemical analyses of plants taken during the growing season from the variously treated plots showed that the plants from plowed soil had a higher potassium content than those from unplowed soil. There was no difference, however, in the exchangeable potassium contents of plowed and unplowed soil.

In another experiment located on Tama soil, the corn plants on unplowed soil showed extreme nitrogen-deficiency symptoms, whereas no nitrogen-deficiency symptoms occurred in corn on the plowed soil. These differences in nitrogen nutrition were confirmed by nitrogen analysis of corn plant samples and by nitrate analysis of soil samples taken from the variously tilled plots.

The results obtained show that the poorer growth made by corn on unplowed soil as compared with plowed soil is due principally to various nutrient deficiencies and that the method of tillage employed in preparing the seedbed has a marked effect on the availability of soil potassium and nitrogen to corn.

The Response of Various Forage Grass and Legume Seedlings to Phosphate Fertilization Under Greenhouse Conditions.—R. R. Robinson, *U. S. Regional Pasture Research Laboratory, State College, Pa.*

THE seedling response of four grasses and four legumes to six levels of phosphate fertilization was determined in the greenhouse on Hagerstown soil. The grasses were timothy, orchard grass, bromegrass, and tall oat grass; the legumes were alfalfa, Ladino clover, red clover, and birdsfoot trefoil. Yields of both tops and roots were determined 9 to 12 weeks after seeding. At the lower phosphate levels alfalfa and red clover produced more dry matter than timothy, orchard grass, and bromegrass, but at the higher levels of phosphate fertilization the grasses yielded more than the legumes. Each of the four grasses showed greater increases in yields of dry matter and greater percentage increases in yield from high rates of phosphate than did any of the legumes.

Results obtained with different levels of lime, potash, nitrogen, and manure indicated that the differences in phosphate response of the grasses and legumes could not be attributed to a deficiency of nutrients other than phosphorus.

A Comparison of Potassium Chloride and Potassium Metaphosphate As Sources of Potassium For Plants.—R. F. CHANDLER, JR. AND R. B. MUSGRAVE, *Cornell University, Ithaca, N. Y.*

FIELD experiments conducted at Ithaca, N. Y., since 1940 have shown rather consistently that potassium metaphosphate produced higher yields of various agronomic crops than superphosphate and muriate of potash, even though there were no differences in the amounts of phosphorus and potassium applied. Calcium metaphosphate and muriate of potash generally produced lower crop yields than did potassium metaphosphate.

Some preliminary greenhouse studies indicated that the absorption of potassium by ladino clover was considerably less when the potassium supplied was from potassium metaphosphate as compared with potassium chloride. This seemed to be another advantage of potassium metaphosphate because a single application would supply potassium over a considerable period of years without resulting in excessive luxury consumption as would occur with potassium chloride. Field experiments with sudan grass, however, have not shown any great differences in crop composition when the two sources of potassium were compared. Laboratory studies are being conducted to determine whether or not there may be other compositional differences which may account for the higher yields obtained from the potassium metaphosphate applications. The results of these analyses will be presented in the published article.

Effectiveness of Fused Phosphate of Different Particle Size.—GILBERT L. TERMAN, *University of Kentucky, Lexington, Ky.*

IN FIVE experiments conducted over a 3-year period on three soils, several different size separates of particles of fused phosphate fertilizer were sieved out and tested in pot cultures in the greenhouse for availability of the phosphorus to Sudan grass and wheat. The fused phosphate particles were compared with similar separates of triple superphosphate particles in two of the experiments. All tests were made in soils deficient in phosphate. The various phosphate separates were mixed with the soil at a rate to furnish 75 pounds of P_2O_5 per 2,000,000 pounds of soil.

The coarser separates of fused phosphate tested, 10–20 mesh and 40–60 mesh, were much less effective as carriers of phosphorus than finer particles, as measured by growth of Sudan grass and wheat. Effectiveness, as measured by growth and phosphorus content of the crops and percentage recovery of added phosphate, increased in general with decrease in particle size, which is accompanied by an increase in the rate of solution. The finest separate tested (below 270 mesh), however, was somewhat less effective for growth of sudan

grass than three intermediate separates varying from 60–270 mesh. Liming the soil decreased the effectiveness of larger particles.

Greenhouse tests of triple superphosphate of different particle size gave entirely different results. The larger particles of this phosphate gave somewhat higher yields, and effectiveness decreased with decrease in particle size. This results from the tendency of soil to fix phosphate in forms not readily available to plants. With decreasing particle size, a given amount of phosphate contacts an increasing amount of soil, and a larger portion tends to be fixed. The same condition is true for fused phosphate, but the effect is lessened by the slower rate of solution of particles of a given size.

Field tests of lots of fused phosphate ground to pass different sized screens did not give the same results as were found in greenhouse tests. In tests conducted at three locations in Kentucky, no significant difference in yields of corn and wheat was found on plots receiving triple superphosphate and lots of fused phosphate, 6 mesh and finer, 40 mesh and finer, and 80 mesh and finer, as the source of phosphate.

Effects of Certain Fertilizer and Lime Treatments on Some Chemical Properties of Cecil Sandy Loam.—G. A. STRASSER AND S. S. OBENSHAIN, *Virginia Agricultural Experiment Station, Blacksburg, Va.*

AN investigation of the pH, organic matter content, total nitrogen, and cation exchange properties of the soil of the 18-year-old rotation plots at Chatham, Va., was carried out. Individual soil samples were taken of each of the 26 subplots which compose the experiment. After the chemical analyses were completed, the data were analyzed statistically.

As a result of this investigation, the following conclusions are presented: (1) Application of ground limestone which resulted in increased crop yields also tended to increase organic matter content and cation exchange capacity. (2) The lower soil reaction of the unlimed plots seemed to be more effective in retaining a larger percentage of the total dry matter produced as soil organic matter. (3) A significant positive correlation was found between soil organic matter and cation exchange capacity. (4) There seemed to be no significant correlation between fertilizer treatments, crop yields, and carbon-nitrogen ratio. (5) Applications of different amounts of superphosphate and their combinations with muriate of potash and muriate of potash and nitrate of soda apparently have had no effect on the amount of exchangeable calcium, magnesium, and hydrogen present. (6) Exchangeable potassium seemed unaffected by fertilizers not containing potassium, but showed a marked increase on the plots receiving potassium in a mixture. (7) Applications of ground limestone have resulted in large increases of exchangeable calcium and magnesium, increases in exchangeable potassium, and marked decreases in exchangeable hydrogen and pH values. Percentage base saturation was also greatly increased by ground limestone applications.

Some Areas in the United States Associated with Deficiencies of Cobalt and Other Elements in the Soil.—KENNETH C. BEESON AND SEDGWICK E. SMITH, *U. S. Plant, Soil, and Nutrition Laboratory, Ithaca, N. Y.*

NUTRITIONAL troubles in cattle have been observed in several localities along the Atlantic Coastal Plain and in the northern and northeastern parts of the United States. Examination of forages from these areas indicates deficiencies of cobalt as a possible explanation, but other mineral elements are undoubtedly lacking in amounts adequate for good nutrition. The possibility of increasing the nutritive value of forages by fertilization, particularly with superphosphate, has been attempted, but so far the results, using sheep, have been negative. Maps will be presented.

The Effect of Limestone and Fertilizer Treatments Upon the Growth and Composition of Spinach.—F. T. TREMBLAY AND S. C. VANDECAVEYE, *Western Washington Experiment Station, Puyallup, Wash.*

THE growth and composition of spinach was determined when the plants were grown on three typical western Washington soils previously subjected to limestone and fertilizer treatments.

The dry weights of the spinach plants were increased on all three soils by the addition of ground limestone at the rate of 3 tons per acre, irrespective of fertilizer treatment. On the Kitsap silt loam the spinach plants were incapable of continued growth without the addition of lime. Leaf analysis indicated that phosphorus was the limiting factor in plant growth and was subsequently released upon the addition of calcium.

Yield data and leaf analysis studies indicated that calcium, nitrogen, and potassium were limiting factors in spinach growth on the Chehalis silty clay loam.

The production of spinach on the Puget soil was not appreciably increased by the addition of limestone. However, the fertilizer treatments were effective in increasing the yield of spinach on this soil.

The Response of Hemp to Fertilizers in Iowa.—C. A. BLACK AND A. J. VESSEL, *Iowa State College, Ames, Iowa.*

IN 1943, eight replicated fertilizer trials were conducted on six soil types in the hemp-growing area of north-central Iowa. In experiments employing nitrogen (25 pounds N per acre), phosphorus (50 pounds P_2O_5 per acre), and potassium (25 pounds K_2O per acre), singly and in all combinations for hemp, nitrogen gave the most benefit, followed in order by phosphorus and potassium.

The 25-pound rate of nitrogen was insufficient to give maximum yields. Nitrogen added at the rate of 100 pounds per acre in several nonreplicated tests produced substantial yield increases over those obtained with the 25-pound rate.

The response to phosphorus was limited by the deficiency of nitrogen in a number of cases. Yield increases from phosphorus fertiliza-

tion generally were larger where nitrogen also was applied than they were where phosphorus was used alone or with potassium. Combinations of nitrogen and phosphorus produced higher yields than did either nitrogen or phosphorus applied singly.

Potassium in general did not increase the yield of hemp, except in in the highest yielding fields where it appeared to be of some value in combination with nitrogen and phosphorus.

Seven replicated fertilizer trials were conducted in 1944. A factorial design was employed with nitrogen at 50 and 100 pounds N per acre, phosphorus at 30 pounds P_2O_5 per acre, and potassium at 20 pounds K_2O per acre. The results from these experiments followed the same general pattern as did those in 1943. Nitrogen was of greatest importance, followed in order by phosphorus and potassium. However, one field well supplied with nitrogen responded mainly to phosphorus and several other fields gave only a small response to phosphorus. The 100-pound rate of nitrogen produced higher yields than did the 50-pound rate. In no experiment did the 100 pounds of nitrogen produce an excessively coarse growth of stalks.

The Growth and Nutrition of Tomato Plants as Influenced by Exchangeable Sodium, Calcium, and Potassium.—D. W. THORNE, *Utah, Agricultural Experiment Station, Logan, Utah.*

CALCIUM and sodium are the two most important ions influencing the nutrition of plants in soils of the arid region. The interrelationships of these and other ions are not sufficiently understood to enable one to interpret results commonly observed in the field. To assist with the problems involved, investigations are being conducted on the influence of calcium, sodium, calcium carbonate, clay, and organic matter on the growth and mineral uptake of plants. In the studies reported here the growth and mineral content of tomato plants were investigated in relation to various ratios of sodium and calcium adsorbed on bentonite clay and mixed with pure quartz sand. For comparison, tests were also made with similar ratios of potassium to calcium. The clay had an exchange capacity of 120. Essential plant nutrient elements were added to the hydrogen clay and the remainder of the exchange capacity was saturated with the desired ratios of the elements being studied. Sixty grams of the clay were mixed with 1,800 grams of sand for each pot culture.

The yield of tomato plants decreased as the sodium concentration exceeded 40% of the exchange capacity, and there was no growth with sodium in excess of 70%. In contrast, growth was not limited until potassium exceeded 60% of the exchange capacity and continued beyond a level of 90% potassium.

The sodium content of the plants increased rapidly and the calcium content decreased with increasing proportions of exchangeable sodium. Potassium showed only a moderate increase and calcium a slight decrease as the percentage of potassium on the clay was raised. There was a tendency for the phosphorus and iron content of the plants to increase with the high levels of potassium on the clay, but variations in the sodium on the clay had no distinct influence on the uptake of either iron or phosphorus.

The data support the theory that the infertility of soils of high sodium saturation is due to the inability of plants to obtain adequate calcium. The results appear to contradict the hypothesis that high potassium favors iron chlorosis by preventing iron absorption.

A Comparison of Three Nitrogenous Materials for Top-Dressing Vegetable Crops.—W. G. Woltz and R. L. Carolus, *Virginia Truck Experiment Station, Norfolk, Va.*

EASTERN Virginia farmers have relied almost exclusively upon sodium nitrate as a nitrogen carrier for top-dressing spinach. Spinach, being a quick-growing crop from which the leaves are harvested, care must be exercised in fertilizing both from the standpoint of maintaining a readily available supply of plant nutrients, especially nitrogen, and of preventing burning injury. Farmers may apply as much as 125 to 250 pounds of nitrogen per acre on one spinach crop.

With the prospect of large amounts of new ammonium nitrate products becoming available for agricultural purposes, field experiments were conducted to test the relative merits of sodium nitrate, a neutral ammonium nitrate, and an ammonium nitrate treated with an inert material to improve its physical condition for top-dressing purposes. Yield data, soil reaction data, and ammonia and nitrate analyses of the soil are presented.

There were no significant differences in spinach yield between the three materials in the 1943 fall crop. Spinach receiving sodium nitrate had a lighter green color than the spinach receiving the ammonium nitrate materials. The differences in soil reaction between the three materials varied as much as 1 pH unit, with the soils receiving ammonium nitrate showing the more acid reaction. Changes in soil reaction appear to be influenced by the amount of rainfall and the time of rain after the materials are applied, which one should expect from a theoretical point of view. From plant tests and yield data the plants appeared to have been able to acquire ample nitrogen for excellent growth from all of the materials.

Nitrogen and Phosphorus Levels in Relation to Potato Yields During Dry Seasons.—R. L. Carolus and W. G. Woltz, *Virginia Truck Experiment Station, Norfolk, Va.*

THE influences of fertilizer treatments, consisting of nitrogen, phosphorus, and potash at three levels and of calcium at two levels, in a factorial test involving 54 ratios, on the tuber yield, plant composition, and soil nutrients are presented. During each of the four seasons a drought reduced the yield somewhat below the normal for the area. Under these conditions large quantities of nitrogen in the fertilizer reduced the yield markedly unless the fertilizer contained large amounts of phosphatic material. The minimum quantity of nitrogen (60 pounds to the acre) with the minimum quantity of phosphate (80 pounds to the acre) produced from 30 to 80% more tubers than the maximum quantity of nitrogen with the minimum

quantity of phosphate. With larger amounts of phosphate the detrimental influence of large quantities of nitrogen on yield was substantially reduced.

Plant tests indicated excessive quantities of soluble nitrogen in plants from plots fertilized with the maximum amount of nitrogen. Soluble phosphorus was generally found in the plants at a level bordering on a near deficiency. These results indicate that under conditions of inadequate rainfall during the growing season nitrogen may accumulate from year to year but that phosphatic materials are readily fixed in an unavailable state. Under acid soil conditions, conducive to phosphorus fixation, fertilizers containing large quantities of phosphate appear desirable for the potato crop, especially after periods of drought.

The Effect of Different Levels of Nitrogen, Phosphorus, and Potash Applied at Different Times During the Growing Season on the Yield of Sugar Beets and the Nitrogen Content of Sugar Beet Tops.—J. F. Davis, W. D. Batan, and R. L. Cook, *Michigan State College, East Lansing, Mich.*

IT HAS been frequently observed in Michigan that the practice of growing sugar beets directly after alfalfa or sweet clover in a rotation results in significantly increased yields of both roots and tops. The appearance of the plants suggest that the additional nitrogen supplied by the legume is one of the causal agents. However, generally poorer stands occur when beets follow alfalfa or sweet clover in a rotation than when following corn or beans. It was thought that possibly if chemical nitrogen were supplied as a side-dressing throughout the growing season, the increase in yield might be secured without sacrificing stand. An experiment was set up to study the effects of three factors, time of application, nitrogen levels, and phosphorus-potash levels, associated with side-dressing sugar beets during the growing season. The experiment was laid out as a $3 \times 3 \times 3$ factorial design, with four replications, and with the triple intersection confounded with blocks in order to improve the precision. Data on the effect of the various treatments on the yield of roots and tops, stand, and nitrogen content of the tops are presented together with a short explanation of some of the statistical procedures involved in an experimental design of this nature.

Nitrogen Fertilizer Experiments with Flue-cured Tobacco on Granville Sandy Loam.—W. Husmann, *Virginia Agricultural Experiment Station, Blacksburg, Va.*

FROM 1940 until 1944, field experiments with flue-cured tobacco on Granville sandy loam were conducted at Chatham, Va., to compare the efficiency of several combinations of organic nitrogen carriers. Included were activated sewage sludge, processed tankage, castor pomace, fish meal, cottonseed meal, soybean meal, urea, and ammonium nitrate limestone (ANL).

Considerable difficulties were encountered when the value per acre of the various years were to be compared with each other. The prices

for tobacco between 1940 and 1944 for the same grades changed considerably. In certain grades, particularly the lower quality grades, the value quadrupled.

These experiments prove that there is very little if any significant statistical difference between the organic nitrogen carriers, as was to be expected. Distribution of rainfall had a significant influence on the efficiency of castor pomace.

ORGANIC SOIL SUBSECTION

The Effect of Cultivation on the Vertical Distribution of Phosphorus and Potassium in the Profiles of Peat Soils.—E. V. Staker and Francis M. Jornlin, *Cornell University, Ithaca, N. Y.*

SOIL samples from layers of 24 profiles were taken from six widely separated peat areas. Selections were made to obtain samples from virgin areas as well as from adjacent fields under cultivation for periods of time. Profiles were sampled on a layer basis rather than at arbitrary depths. All samples were analyzed for total phosphorus and potassium.

Effect of time of cultivation on the content of phosphorus and potassium was most striking with the surface layers. Here the amounts of these elements increased with the number of years the peat had been farmed. However, this relationship rarely held for the lower layers. In fact, the results indicated that the effect of cultivation generally did not extend beyond the plowed layer.

In every profile, the surface soil contained considerably more phosphorus and potassium than the peat just beneath. For example, the plowed layer of a soil under cultivation for 74 years contained 2,077 p.p.m. of phosphorus and 4,742 p.p.m. of potassium. The next 4-inch layer contained only 360 p.p.m. of phosphorus and 430 p.p.m. of potassium. Invariably more residual potassium than phosphorus was found in the surface layers. In a few profiles, this difference extended to the lower horizons.

The Effect of Varying the Reaction of Organic Soil on the Growth and Yield of the Domesticated Blueberry.—Paul M. Harmer, *Michigan State College, East Lansing, Mich.*

THIS investigation concerns a greenhouse study involving the effect of the mixing of an extremely acid (pH 3.6) and a highly alkaline muck (pH 7.6) in varying proportions, of the application of sulfur to alkaline mucks, and of lime to very acid muck on blueberry growth and yield. Sulfur was also used in varying amounts on slightly acid muck in the field.

The results of this study showed: (1) That the domesticated blueberry cannot survive in alkaline soil and does not do well in a slightly acid soil (pH around 6.0). The best results were obtained when the pH ranged between 4.0 and 5.0. (2) On alkaline mucks sufficient sulfur was required to lower the pH to 4.0 to secure best results, whereas the muck mixture producing best results had a pH of 5.1. (3) The proportion of roots to tops was rather uniform until the pH

was above 6.0, but the roots failed to keep pace with the tops in the sweeter soils. (4) The application of ground limestone to very acid muck (pH 4.0) was beneficial to growth in one instance and of no benefit in another.

The Use of Some Zinc Compounds in Sprays for Potatoes on Muck Soil.—N. K. Ellis, *Purdue University, Lafayette, Ind.*

ZINC sulfate and other zinc compounds were used in potato sprays. When used in combination with regular copper-lime sprays, increased yields may be expected if the yield of potatoes on the plots receiving the regular spray amounts to 250 bushel per acre. Since no disease appeared to affect the growth, the data tend to indicate that zinc may be a limiting factor as a fertilizing element.

The Effect of Various Soil Treatments on Improving An Unproductive Muck Soil.—Donald Comin, *Ohio Agricultural Experiment Station, Wooster, Ohio.*

MANY areas of Ohio's 50,000 acrês of muck or peat soils are considered unproductive by growers of vegetative crops, due to an acid or alkaline condition. Recently, another type of unproductiveness of muck soils has been recognized which condition always occurs on areas continuously cropped for long periods. It more frequently occurs where no crop rotation has been practiced and no green manure or cover crops are grown. In order to determine the cause of this unproductiveness, various nutrient and minor element materials were applied for two seasons previous to the growing of a celery crop in order to satisfy the crop's needs.

The yields revealed only slight differences irrespective of the treatment. Quick soil tests also revealed relatively high nutrient level existing in the soil.

In connection with the minor element and fertilizer applications, a few plots were treated in cooperation with the Station plant pathologists with several soil-sterilizing solutions and salts with the idea that continuous cropping to celery might have resulted in soil organisms antagonistic to root growth. The results indicate that the assumption was correct, for the yields were increased manyfold by soil sterilization. The results suggest that crop rotation, either with or without the use of green manure and cover crops, may provide an economical remedy.

Iowa Peat Profiles.—J. B. Peterson, *Iowa State College, Ames, Iowa.*

AS PART of the work of characterizing the profiles of peat soils in Iowa, some 30 profiles were sampled and analyzed. Most of these profiles are acid in the upper layers, becoming neutral or alkaline only when the remnants of mollusk shells are reached just above the underlying clay. A few bogs are alkaline to the surface and a few are quite acid, but, in general, the pH varies from 5 to 7, with the median at 6.2.

The lignin expressed as percentage of the organic fraction varies around 60%. The unplowed areas are slightly lower in lignin in the black, amorphous surface layer than in the underlying layers of brown fiber. The reverse is true where the land has been plowed. There is a marked rise in lignin content in the shell-bearing layer just above the clay. The total nitrogen content of the profiles is fairly uniform, ranging from 2 to 3%. Exceptions occur in the layers high in minerals, where the nitrogen is low, and in the reddish layers of well-preserved hypnum moss found in some bogs, where the nitrogen content is exceptionally high.

SECTION V—SOIL GENESIS, MORPHOLOGY, AND CARTOGRAPHY

The Nature and Relationships of Laterite and Earthy Iron Ores and Their Parent Ultramafic Rock.

—GEORGE H. KEMMER AND ROBERT L. PENDLETON, *U. S. Dept. of Agriculture, Washington, D. C.*

IN the coastal regions of Surigao Province, northeastern Mindanèo, abundant rainfall and high temperatures throughout the year rapidly weathered the ultramafic rock, developing two types of profiles. In the first type, where the soil developed on the peneplain of low relief, a laterite horizon developed within the soil profile.

Initiated by a considerable elevation of the land above the sea, a new cycle of erosion commenced. This lowered the water table. Under these altered conditions the weathering of the parent rocks was accelerated, while the development of laterite was precluded. The final weathering product of this second type is a friable red lixivium of great depth, and very high in iron. Below the thick red horizon is one of yellowish color. Portions of the former peneplain surface still remain and are capped by laterite, the eluvial horizon having been eroded.

A survey and evaluation as ores of these weathering products involved drilling a large number of holes through the soil and underlying horizons and into the parent rock. Hundreds of analyses were made of the drill-hole samples.

A representative selection from the analytical data is presented and the pedological significance of the results pointed out.

Some Investigations of Clay Formation and Movement in Two Claypan Soils.

—E. P. WHITESIDE, *University of Illinois, Urbana, Ill.*

DETAILED mechanical analyses and volume weight determinations on representative profiles of Putnam silt loam from Missouri and Cowden slit loam from Illinois show that the former soil contains a greater proportion of clay in the profiles. These data, together with a knowledge of the loess deposits from which they were formed, indicate that about one-half of the clay in the upper 40 inches of the Cowden silt loam has appeared during soil formation. The bulk of the clay is found in the finest clay fractions.

Calculations, made on the basis of certain assumptions, indicate that some movement of clay has taken place within these soil pro-

files. While a greater part of this movement of clay has taken place in the finer clay fractions, some movement of the coarser clays is also indicated. The exact amount of the movement is not yet known and the calculations give only minimum values.

It appears from available information that the greater clay content of the Putnam silt loam profile is probably related to a higher clay content of the loessial deposits from which it has developed.

SECTION VI—SOIL TECHNOLOGY

Climate and Soil Moisture.—C. W. Thornthwaite, *Soil Conservation Service, Washington, D. C.*

RECENT studies have made it possible to determine approximate rates of evaporation and transpiration from land surfaces in different parts of the country and under different kinds of plant cover and different soil types. Evapo-transpiration is related primarily to precipitation, temperature, and length of day; it is virtually independent of type of plant cover and soil type. Like precipitation, it is a climatic phenomenon.

Knowing the daily loss of water from the land surface through evaporation and transpiration and the gain to the surface due to precipitation, it becomes possible to compute the amount of moisture in the root zone by means of a simple accounting system. This has been varified by comparing computed values of soil moisture at five different locations in northeastern United States with actual moisture determinations. The method makes it possible to compute soil moisture for any place and time for which data of temperature and precipitation are available.

The method provides a new definition of drought. It indicates the amount by which rainfall fails to meet plant needs for water, and tells when supplementary water should be applied to prevent soil desication. The area in which supplementary irrigation could be employed profitably is outlined.

Tillage Practices in Relation to Soil and Water Conservation and Crop Yield in Iowa.—G. M. Browning, R. A. Norton, and E. V. Collins, *Iowa State College, Ames, Iowa.*

STUDIES to determine the effect of the following tillage treatments on soil and water conservation and crop yields were continued at the Clarinda Experimental Farm and at five other locations in Iowa in 1944: (1) Plowed and surface planted, (2) plowed and loose-ground listed, (3) hard-ground listed, (4) subsurface tilled with residue on the surface, (5) subsurface tilled and disked, and (6) disked. Residues included corn stalks, rye and vetch, red clover, and sweet clover, and the crops grown were corn, oats, and soybeans.

On the Marshall silt loam soil less differences were noted in plant growth between the tillage treatments in 1944 than in 1943. Yields of corn were highest on the hard-ground listed plots for all residue studies, while the disked or subsurface-tilled plots gave the lowest yield in most experiments. Stand was considerably lower on the loose-

ground listed plots, due to silting in of the furrows. Weed control was more difficult on the disked and subtilled plots.

In general the effect of different tillage methods has varied considerably, depending upon climatic conditions, the type of soil, the type of residue, and past management of the soil. Soils that have been well managed in the past and which have favorable structural conditions showed only small differences in the plant growth, regardless of treatment, while poorly managed soils showed large responses to tillage practices such as plowing which loosens the soil more thoroughly than subsurface tillage or disking.

Some Factors Affecting Design of Tillage Machinery and Proposed Approach to Their Evaluation.—I. F. Reed, Sr., *U. S. Dept. of Agriculture, Auburn, Ala.*

LABORATORY work by soil scientists and agricultural engineers shows the effect of colloid films, shear values of certain soils, effects of soil factors on soil and metal friction, factors both soil and design affecting scouring, and the true reaction of soils over moldboard surfaces. It was found that it was not possible to measure the effects of these factors under the varying conditions in the field. This led to the establishment of the Tillage Machinery Laboratory at Auburn, Ala., which is designed to permit studying full size tillage implements under controlled condition of both the implement and the soil. It is proposed that a National Tilth Laboratory be established to enable determining plant response under controlled conditions of soil, air, and water. This laboratory should help soil scientists and agronomists to determine the ultimate soil conditions required for different crops and to develop measures for determining and describing these conditions. If given the specifications of soil tillage to be met, the agricultural engineer should be able to develop equipment to do the job effectively and economically.

Rotary Mixing in Soil Stabilization.—Harry J. Seaman, *Seaman Motors, Milwaukee, Wis.*

REQUISITES in treatment of an area by means of any soil stabilization process to obtain maximum weather-resistant and load-bearing characteristics are a proper foundation or base and an intimate mixture of soil and binder. These factors are equally true in processing with either deliquescent or waterproofing chemicals.

Earth consolidation in the foundation may be required, especially in grade fills. In this case, as well as in the pulverization of friable soils prior to stabilization, the Seaman Pulvi-Mixer, a machine in which power driven tines operate rotationally at high velocity within a mixing chamber, disperses organic matter which would mitigate against compaction and, by completely mixing the various sizes of ingredients, assists in voidage control. In earth consolidation, where water is employed to lubricate soil particles to further compaction, tests show as much as 12% improvement in density with the use of this machine.

In-place-mixing operations in soil-cement stabilization require a close control of the water increment. The Pulvi-Mixer, by decreasing and standardizing the mixing time required, reduces the uncertainties of evaporation and because of a more complete mixture tends to prevent water migration.

In bituminous construction because aeration of materials is augmented by the tine action, solvent content is lowered more quickly and a more rapid set is obtained. Migration of bitumen is lessened and, because of the "carry" of materials within the mixing chamber of the machine, lean and rich spots are substantially reduced.

Engineering Properties of Soils Correlation with Fundamental Physical Factors.—HANS F. WINTERKORN, F. LEICESTER CUTHBERT, AND I. GEORGE MORRISON, *Princeton University, Princeton, N. J.*

THE physical properties of soils and their colloids are very significant with respect to their susceptibility to stabilization for roads and airport construction. For this reason a study has been made of the properties of soil materials taken from the B-horizons of 11 different soil types belonging to different series. This horizon is commonly employed in stabilization, while the A-horizon is wasted.

The colloid (minus 2 micron) fractions of these soils have been separated, and a comparison has been made between the physical properties of the whole sample, its colloid fraction, and its residue fraction, consisting of particles all greater than 2 microns in diameter. These data are discussed in the light of actual laboratory stabilization tests on the soils.

Fully Mechanized Farming on the Agronomic Unit Basis.—ROBERT E. HORTON, *Hydraulic Engineer, Voorheesville, N. Y.*

IN this paper farming is viewed as a creative engineering industry capable of a higher degree of mechanization than now exists. The author points out that neither the earning power nor stability of income of the individual farmer is as great as in more fully mechanized and economically organized industries. Full mechanization requires larger farming units and the paper presents in some detail problems and results which would apparently follow from farming on an agronomic unit basis instead of by individual farms. An "agronomic unit" is described as a group of contiguous farms with line fences removed and the land operated as a single unit by the owners, with full mechanization and central administration.

The following advantages of the use of agronomic farming units and full mechanization are discussed: (1) Timing of crops and harvest, permitting greatly increased load factor for each mechanized unit; (2) longer and better tillage lines, with less turning and increased speed of operation; (3) reduction in number of mechanized units and farm labor required; (4) better opportunity for contour cultivation and soil-moisture conservation; (5) the use in many cases of much larger tractor units than can be economically used on a small

individual farm; and (6) operation of the agronomic unit by the farm owners but on the basis used in industrial plants, with specialized direction of each managerial function.

Using experience gained in the closely related industry of electric energy production, attention is directed to the importance of load factor and crop timing as a means of reducing both capital and labor in farm operations. Problems arising in the organization and operation of agronomic farming units are considered, including by-laws, provision for settlement of disputes and disagreements, desirable legislation, working capital, management, and labor.

Much that is said regarding the opportunities for fuller mechanization resulting from abolition of line fences and laying out of tillage units on an agronomic unit basis applies equally well to individual or corporation-owned large farms made up from what were originally smaller farms. The author believes that the retention of the individual farmer as the farm owner is desirable and the agronomic farming unit is suggested as a means of accomplishment of full benefits of centralization and mechanization, with the original farm owners still retaining title to their lands and residences thereon.

The purpose of the paper is stated to be to bring out the disadvantageous position of the individual farmer as compared with fully mechanized industry, with a view to promoting constructive discussion and providing remedial measures, whether these remedial measures are the same as those used for illustration in the paper or not.

AGRONOMIC AFFAIRS

THE AMERICAN SOCIETY OF AGRONOMY IN 1944

IN this, the third year of the war, agronomists and soil scientists can see better than ever the results of the application of their research. Members of this Society and the institutions with which they are associated laid the foundation for the remarkable increase in food production American farmers achieved in 1944. What is that record? Briefly stated, it is a 33% increase in crop production as compared with the average for 1935–39. This was accomplished with only a 3% increase in the acreage of crop land. How was it achieved? It is of course difficult to assign the increase that should be credited to the different factors, but a careful estimate[1] breaks down the 33% increase as follows:

Better than normal weather	8 to 10%
Agronomic practices:	
Improved varieties of crops	4 to 5%
Increased liming and fertilization	4 to 5%
Adjustments in land use and cropping systems	2 to 4%
All other factors	11 to 14%

The most spectacular increases have been in the major war crops, such as peanuts and soybeans. The farm production record of 1944, I am sure, is a source of pride to members of this Society and offers convincing proof of the effectiveness of agronomic research.

The work of the Society, particularly of several of the committees, has been seriously handicapped by conditions associated with the war. Despite such difficulties, however, all of the functions of the Society have been carried on satisfactorily as indicated by the reports of the officers and committees. The officers responsible for developing the program of the annual meeting had made excellent progress before the decision was made to cancel the meeting. They and the members preparing papers are to be commended for the way they have carried on with the publication of abstracts and the articles that will appear in the JOURNAL in 1945 and in the PROCEEDINGS of the Soil Science Society.

The annual meeting of the Society was cancelled by the almost unanimous vote of the Executive Committee and Committee Chairmen of the Agronomy and the Soil Science Societies. This action was taken at the repeated requests of the Office of Defense Transportation and after a large number of organizations, including important scientific societies, had complied with the request. The action represents another contribution of the Society to the war effort.

Cancellation of the annual meeting presented an unusual situation to your officers. The following actions were taken by the Executive Committee:

[1]Production Adjustments—1945 and Postwar. JOHNSON, SHERMAN E., Bureau of Agricultural Economics, Annual Agricultural Outlook Conference, Washington, D. C., Nov. 14, 1944.

1. Abstracts of papers to be presented at the annual meeting were requested for publication in the December issue of the Journal.
2. Reports of all officers and committees were requested for publication in the December issue of the JOURNAL.
3. Officers and committees for 1944 were requested to serve for a second year until the 1945 annual meeting.
4. The election of Fellows was omitted for this year.

In all matters of policy the officers of the American Society of Agronomy and the Soil Science Society of America conferred and took joint action.

The 1945 annual meeting should be one of the best in the history of the Society. Your officers will strive to that end and with your continued support will make it a memorable meeting. I especially request the assistance of the members to the men charged with the responsibility of developing the program.

The Society is proud of its members in the Armed Forces of the United States and the United Nations. We trust events of the next year will enable many of them to be with us at the 1945 annual meeting.—F. W. PARKER, *President of the Society.*

REPORTS OF OFFICERS AND COMMITTEES

REPORT OF THE EDITOR

THE JOURNAL has weathered another year of war with little visible effect. The quality of the paper has deteriorated somewhat, but the supply has always been adequate, and, all things considered, we are fortunate to have had all the paper we needed when we needed it. The use of more zinc than copper halftones has not enhanced the general appearance of the JOURNAL, but it has been a real war time economy in essential materials and in cost of production. Despite labor shortages and heavy demands on the facilities of the shop, the printers have delivered the JOURNAL very nearly on time throughout the year.

For the first time since Pearl Harbor, however, we are beginning to see the effect of the war on the output of manuscripts. This made itself apparent late in the summer of 1944 and is emphasized by the fact that we have at this time (October 20) only 5 approved papers awaiting publication as compared with 22 papers on hand at this time last year. There are in the hands of reviewers, or in the author's hands for revision, 16 papers as compared with 10 at this time last year. In other words, we had a "backlog" of 32 papers in 1943 and now have only 21.

Undoubtedly several papers that would have been presented at the annual meeting this year will be offered to the JOURNAL for publication and will prove acceptable. Based on past experience, however, we do not anticipate any great number of papers from this source. The JOURNAL should be in position during 1945, therefore, to offer fairly prompt publication of acceptable material.

To summarize briefly, the 1944 volume of the JOURNAL will measure up in number of pages quite favorably with recent volumes. It will contain 95 contributed articles, as compared with 107 last year, it will have 29 notes, an increase of 10 over the 1943 volume, and 15 book reviews, making a total of 139 contributions of all types. The publication in the December 1944 number of the abstracts of papers that were to have been presented at the annual meeting accounts in some measure for the reduced number of contributed articles published this year.

While on the subject of the JOURNAL, it may be of passing interest to know how papers progress from the time of their receipt in our office until publication. While our figures have no real significance in that each paper is a case unto itself, we find manuscripts remain in the hands of the reviewers for an average of 40 days, with a range, according to our manuscript records, of 5 to 152 days for a long series of papers in 1944. Where manuscripts are returned to authors for revision, a period averaging 30 days elapses before the papers are returned to us, with a range of 5 to 82 days. Once a paper was approved for publication this past year, it found its way into the JOURNAL within 3 to 5½ months, or within about 4 months on the average. This checks fairly close with the expectation in 1944 of publication within 6 months of receipt of the manuscript in our office.

Our thanks to all the advertisers who have stood by the JOURNAL so loyally this past year are gratefully acknowledged. We trust that throughout the year you have read and benefited from the war bond and anti-inflation advertising the JOURNAL has carried as a service to the United States Treasury Department. We have forwarded to the Secretary of the Society for preservation in the archives a citation awarded to the JOURNAL by the Treasury Department in recognition of cooperation in their advertising campaign.

At the request of the President we acted during the year as chairman of a joint committee of the American Society of Agronomy and the Soil Science Society of America to prepare a folder for use in stimulating interest in the two organizations. Other members of the committee were R. J. Garber, F. D. Keim, G. W. Conrey, and H. J. Harper. Copies of the folder have been distributed to the several state representatives of the two societies and additional copies may be obtained from the office of the Secretary.

We are deeply indebted to the Associate Editors, Dr. R. J. Garber and Dr. Emil Truog and their consulting editors and reviewers, for their constant and generous sacrifice of time and effort in meeting the responsibilities imposed upon them as members of the Editorial Board of the JOURNAL.

Respectfully submitted,
J. D. LUCKETT, *Editor*.

REPORT OF THE SECRETARY

THE membership changes in the Society during the past year are as follows:

Members, October 29, 1943		1,209
New members	148	
Reinstated members	8	
Dropped	95	
Deceased	4	
Net increase		57
Membership, October 31, 1944		1,266

The changes in subscriptions are as follows:

Subscriptions, October 29, 1943		519
New subscriptions	76	
Dropped	23	
Net increase		53
Subscriptions, October 31, 1944		572

The paid up membership and subscription list by states and countries is as follows:

	Members	Subscribers
Alabama	17	2
Arizona	17	6
Arkansas	12	6
California	69	15
Colorado	16	1
Connecticut	14	5
Delaware	4	2
District of Columbia	56	17
Florida	27	6
Georgia	27	5
Idaho	9	3
Illinois	63	20
Indiana	38	4
Iowa	40	5
Kansas	39	3
Kentucky	15	5
Louisiana	24	8
Maine	4	1
Maryland	55	8
Massachusetts	9	6
Michigan	28	4
Minnesota	44	9
Mississippi	17	4
Missouri	18	8
Montana	8	6
Nebraska	36	4
Nevada	3	1
New Hampshire	1	1
New Jersey	17	6
New Mexico	12	4
New York	61	43
North Carolina	26	7
North Dakota	19	1
Ohio	43	9
Oklahoma	12	6
Oregon	21	5
Pennsylvania	29	10
Rhode Island	6	0
South Carolina	19	2
South Dakota	10	1
Tennessee	18	4
Texas	56	22
Utah	19	7
Vermont	4	1
Virginia	17	3
Washington	21	6
West Virginia	7	1
Wisconsin	40	7
Wyoming	5	2
Alaska	1	1
Canada	30	29
Cuba	3	3
Hawaii	5	11
Puerto Rico	4	4
Africa	3	33
Argentina	8	8
Australia	1	29
Bolivia	0	1
Brazil	3	7
British Guiana	0	1
British West Indies	0	1
Ceylon	0	3
Chile	4	1
Colombia	4	2
Egypt	0	1
Eire	0	2
England	0	21
Fiji Islands	0	1
Guatemala	1	2
Haiti	2	1
Honduras	1	1
Iceland	0	1
India	3	17
Iraq	0	1
Mauritius	0	1
Mexico	6	3
New Zealand	0	7
Palestine	1	1
Peru	4	3
Portugal	0	4
Salvador	1	1
Scotland	2	1
Spain	1	2
Uruguay	2	0
U. S. S. R.	2	50
Venezuela	2	2
Wales	0	3
Total	1,266	572

Once again we have increased both in numbers of member and subscribers. The increase in membership is one more than last year. When we consider that most of the young men, to whom we usually look for new members, are in the Service, the increased membership is even more remarkable. However, many of these young men have shown their continued interest in agronomy by joining the Society during the past year. With the present upward swing in membership, in spite of present conditions, I feel we may look forward to even greater increases after hostilities cease.

The increase in subscriptions is likewise grafitying. Over half of the increase is the result of an order for 50 subscriptions for the U. S. S. R. which is apparently

resuming scientific work in the reconquered territory. Undoubtedly other countries will also renew subscriptions as they are liberated. Judging from the increases in both members and subscribers it would appear that we might need to increase the number of copies printed as soon as the paper shortage is over.

The efforts of the various members, and particularly the state representatives of the Society, in keeping up interest is deeply appreciated. With your continued support your Society will continue to grow.

Respectfully submitted,
G. G. POHLMAN, *Secretary.*

REPORT OF THE TREASURER

I BEG to submit herewith the report of the Treasurer for the year ending October 31, 1944.

RECEIPTS

American Society of Agronomy	$14,288.27
Soil Science Society of America	4,392.65
Marbut Memorial Fund	109.75
Endowment Fund, International Society of Soil Science	15.75
Total receipts	$18,806.42
Balance on hand in bank, October 31, 1943	1,825.35
Total income	$20,631.77

DISBURSEMENTS

American Society of Agronomy	$12,774.47
Soil Science Society of America	5,117.90
Marbut Memorial Fund	9.12
Total disbursements	$17,901.49
Balance in bank, October 31, 1944	2,730.28
Balance in Savings Bonds	2,580.00
Total assets, October 31, 1944	$ 5,310.28

These assets are divided as follows:

	Cash in bank	Savings bonds	Total
American Society of Agronomy	$2,260.57		$2,260.57
Soil Science Society of America (deficit)	−1,348.36		−1,348.36
Marbut Memorial Fund	407.57		407.57
International Society of Soil Science	1,152.48		1,152.48
Endowment Fund, I.S.S.S.	258.02	$2,580.00	$2,838.02
Total assets	$2,730.28	$2,580.00	$5,310.28

A breakdown of receipts and disbursements for the American Society of Agronomy for the year ending October 31, 1944 is as follows:

RECEIPTS

Convention receipts	$ 879.50
Miscellaneous receipts	8.60
Advertising	1,196.90
Reprints	1,662.23
JOURNALS sold	601.15
Subscriptions, 1943	250.00
Subscriptions, 1944 (old)	2,322.30
Subscriptions, 1944 (new)	345.70
Subscriptions, 1945 (advanced)	628.50
Dues, 1943	112.50
Dues, 1944 (old)	5,300.93
Dues, 1944 (new)	725.11
Dues, 1945 (advanced)	134.00
Index	15.15
Abstracts	5.70
Student Essay Fund	100.00
Total receipts	$14,288.27
Balance in cash, October 29, 1943	746.77
Total income	$15,035.04

DISBURSEMENTS

Printing the JOURNAL, cuts, etc		$ 8,910.00
Salary of Editor		736.80
Postage, Editor and Secretary		194.15
Miscellaneous printing		216.25
Mailing Clerk and Stenographer		1,268.13
Refunds, checks returned, etc		72.35
Expenses for meetings		1,077.39
Miscellaneous		299.40
Total disbursements		$12,774.47
Total income	$15,035.04	
Total disbursements	12,774.47	
Balance in bank, October 31, 1944		$2,260.57

The balance on hand of $2,260.57 is $1,513.80 more than we had on hand a year ago. Expenses have been somewhat lower, particularly the cost of printing the JOURNAL, and receipts from membership dues and JOURNALS sold have increased. I hope this trend may continue and that we can look forward to another good year for the Society.

Respectfully submitted,

G. G. POHLMAN, *Treasurer*.

AUDITING COMMITTEE

THE members of the Auditing Committee have this day (November 24, 1944) examined the books of the Treasurer of the American Society of Agronomy and of the Soil Science Society of America, and find, to the best of our knowledge and belief, the accounts correct as reported.

R. J. FRIANT, *Chairman*
I. C. GALVIN
EDWARD H. TYNER

UNION OF AMERICAN BIOLOGICAL SOCIETIES

THE Union of American Biological Societies was organized primarily to sponsor *Biological Abstracts*. When organized in 1923, there were 17 member societies; now (1944) there are 34 member societies. In addition to sponsoring *Biological Abstracts*, the Union has undertaken several projects of general interest in the field of biology. Among these recent activities may be mentioned projects to increase the teaching of biology in the secondary schools and to foster closer relationships between the biologists of North and South America.

A Committee on Biological Science Teaching issued a printed report (75 pages) as a result of analyzing 3,200 returned questionnaires out of a total of 15,000 sent out regarding the amount of biology taught or offered in secondary schools, the frequency of various biological subjects in the four-year high school curriculum, the extent of laboratory work, and sundry other relevant items. As a result of activity of the Committee, particularly the report, the American Medical Association and other medical societies of the United States took some action looking toward more and better instruction in biology, particularly in high schools.

The Union is also participating (two representatives) in the activity of the Cooperative Committee on Science Teaching. This committee has assembled information which should enable it to render effective service either in an advisory or more active capacity in connection with the place of science in the education of men and women mustered out of military service.

The Latin American project is being developed jointly by the Union and the American Biological Society. A committee has prepared a booklet outlining opportunities for biological training and research in the United States that has been translated into Portuguese and Spanish. The brochure describes the organization of scientific education in the United States including biological science in graduate and professional schools, in biological field stations, and in land grant colleges and experiment stations. At the recent meeting (September 13, 1944) of the council of the Union in Cleveland, Ohio, it was reported that the Spanish translation of the booklet would be released by the printer in about two weeks and that the Portuguese translation would be submitted for printing in the immediate future.

Doctor J. E. Flynn reported that *Biological Abstracts* would complete the year in a sound financial condition. Owing partly to the support of biological industries, it is expected that there will be but a small, if any, financial deficit by the end of the year. At present there are about 150 section editors, 3000 collaborators, 1,100 of whom have assumed responsibility for abstracting journals or other publications issued more or less regularly, all serving without pay. After the war, upwards of 2,500 European journals not now available should be abstracted. Tentative arrangements have been made for an exchange of scientific literature with Russia and thus make available, at least in abstract form, much of the Russian scientific literature.

Before adjournment, the Council discussed the need for an over-all biological society such as now exists among the chemists, the physicists, and other scientific groups. It was suggested that perhaps the Union might serve as a framework for building such a society among scientists in biology and agriculture.

R. J. GARBER, *Representative on the Council*

FERTILIZERS

FERTILIZER APPLICATION

BECAUSE of war restrictions on travel and the cancelling of the American Society of Agronomy meetings there was no opportunity for the subcommittee on fertilizer application to meet during the past year. However, the members of the committee continued to participate in and encourage other agricultural workers in studies and demonstrations on fertilizer application.

Much research is in progress on fertilizer placement, particularly on deep placement methods involving plow sole and preplowing broadcast applications and deep drilling after plowing. Results obtained vary with crop, soil, and climatic conditions but in general show sufficient promise to justify continuation of these studies.

Some work is being continued with the use of starter solutions and the use of fertilizers in irrigation waters.

Considerable progress is being made in the development and improvement of mechanical equipment for the practical application of fertilizers for both experimental plots and large-scale field operations.

JOSEPH A. CHUCKA, *Chairman.*

DIAGNOSIS OF PLANT NUTRIENT

THE interference of war and the loss of personnel have made it impossible for this committee to make any progress this last year. A few case histories were assembled and it has been planned to publish these periodically in a special department of the JOURNAL of the American Society of Agronomy. There is a likelihood there will be no activity on the part of this committee until the end of the war.

GEORGE D. SCARSETH, *Chairman.*

FERTILIZER RATIOS

THE committee members have continued with the program of encouraging the agronomist of each state to compile a report of the tonnage of each grade of fertilizer sold in their state for both the spring and fall seasons; this report to be based on confidential reports of sales submitted by each fertilizer company selling in the state. Agronomists were urged to compile such a report, regardless of the fact that several federal agencies are making similar compilations, because of the cooperation involved between the industry and the state agronomists. In the final analysis the industry, the farmers, and the agronomists are the persons most intimately concerned with fertilizer grades sold in each state.

The committee has also given consideration to the problem of the control of grades sold in each state when government restrictions are removed. It is proposed that a list of authorized grades for each state be prepared at an annual conference of representatives of the manufacturers, control officials, and agronomists, either on a regional or state basis. A resolution providing for such a procedure was passed by manufacturers, control officials, and agronomists of the north-central states.

C. E. MILLAR, *Chairman.*

NITROGEN UTILIZATION

NO meeting of the subcommittee was held during the year and the meetings scheduled to be held at the time of the annual sessions of the Society had to be dispensed with. Exploratory correspondence among the membership of the sub-

committee indicated that our function was believed to be primarily advisory to the National Joint Committee as representatives of the Society, although some some further suggestions were offered that would have been considered by the subcommittee if it had had an opportunity to meet. One of our members was serving as chairman of the program committee for the meetings of the National Joint Committee on Nitrogen Utilization, but it seems likely at this writing that these meetings will be cancelled.

FIRMAN E. BEAR, *Chairman.*

ADVISORY COMMITTEE TO THE WAR FOOD ADMINISTRATION

THIS committee has met with the Fertilizer Industry Advisory Committee and with its subcommittees, especially the subcommittee on mixed fertilizers, at each of its meetings during the past year. The committee has attempted to obtain the viewpoint of agronomists throughout the country on adjustments in the fertilizer program of the War Food Administration and present these viewpoints to the War Food Administration and its Industry Advisory Committee. This procedure should contribute very materially to a better mutual understanding of the problems and adjustments required as the oultook on supplies of fertilizer materials changes with the course of the war.

WFO5 has been greatly simplified as it applies to the 1944–45 season. Current problems faced by the committee include the steps which will be needed to assure the continuance of those constructive features of the War Food Administration control program when federal restrictions are lifted. Voluntary agreement with industry on grade limitation seems to be favored by many states to the extent that this is possible. Several states have made legal provision for grade limitation. Some other states are contemplating the enactment of state laws permitting grade limitation by state officials. It appears unlikely that this will become the universal solution immediately. The state and regional meetings of fertilizer industry representatives with state and federal officials and others interested in fertilizer problems for discussion of questions of mutual interest has apparently met with widespread favor and will no doubt continue regularly throughout the fertilizer-consuming area.

On several occasions, while in Washington, the committee has participated in informal discussions with a group under Dr. Sherman Johnson in the Bureau of Agricultural Economics on procedures being worked out for estimating the post-war requirements for lime and fertilizers.

R. W. CUMMINGS, *Chairman.*

SOIL TILTH

THE committee held no meetings this year; but through correspondence, it decided upon a tentative course of action.

The report of last year carried the provision that the report of the committee be submitted to experiment station directors for their consideration. Due to unsettled conditions in the country and scarcity of personnel at the stations, it was believed that it would be a mistake to present the report to the directors at this time. The 1943 report will be submitted to the directors as soon as conditions become more settled.

The committee has found that many research people desire to measure soil tilth, but no one seems to know how to do it. Unfortunately, the committee cannot provide an exact yardstick. Aggregate analyses have been widely used for evaluating structural conditions, but it is usually difficult to interpret these

analyses in terms of crop behavior on soils. Perhaps the chief difficulty arises from the fact that a given soil permeability, for example, can be obtained with an infinity of combinations of different sized aggregates. The same type of difficulty is encountered with other methods proposed for measuring tilth. Obviously, more research is needed before standard procedures for measuring soil tilth can be recommended.

The committee reaffirms the position taken last year, that a strong coordinated national program of soil tilth research is essential to our agriculture. The committee will promote such a program at the appropriate time.

B. T. SHAW, *General Chairman.*

For the American Society of Agronomy	For the American Society of Agricultural Engineers
B. T. SHAW, *Chairman*	L. F. REED, *Chairman*
L. B. OLMSTEAD	M. L. NICHOLS
L. D. BAVER	B. A. JENNINGS
E. N. FERGUS	A. P. YERKES

EXTENSION PARTICIPATION

GREATER participation by extension agronomists at the annual meetings of the American Society of Agronomy has been a subject of discussion at nearly every annual meeting of the Society. It has occupied a major portion of the time at the annual extension breakfasts and has been urged by many of the past Presidents of the Society. However, attendance at the meetings has seldom exceeded 15% of the total number of extension agronomists representing less than 25% of the states.

The work of the Committee on Extension Participation during 1944 was directed toward finding out why more extension agronomists do not attend the annual meetings. This was done by sending a questionnaire to all extension agronomists. The interest in this problem is shown by the fact that 42 replies were received from agronomists in 32 states. Frankness was invited and frankness was exercised in answering the letters.

A copy of each of these letters was sent to the president of the Society who summarized them for the officers of the Society.

The program for the Extension Section was worked out in line with the suggestions made in these letters. One of the most common suggestions was a discussion of the interrelationships of research and agricultural extension. The discussion on this subject was to be lead by Dr. L. D. Baver, Director of the North Carolina Agricultural Experiment Station.

Mr. J. L. Boatman of the Federal Extension Office chose the subject, "The Responsibility of the Extension Agronomist in Post War Production," as the topic for the annual breakfast discussion, while Dr. M. B. Sturgis of Louisiana and Dr. R. H. Bray of Illinois agreed to present papers on "Soil Testing as an Extension Tool."

In addition to these speakers, extension agronomists from several states had agreed to discuss these papers in an informal manner.

CHARLES F. SIMMONS, *Chairman*	IDE P. TROTTER
D. L. GROSS	EARL JONES
ROBERT L. MATLOCK	E. L. WORTHEN
O. S. FISHER	H. C. RATHER

STUDENT SECTIONS

WITH the reduced enrollments in the colleges, student agronomy clubs have been inactive. For this reason no certificates of membership have been issued during the past year and the annual essay contest has been withheld until such time that the number of students will assure adequate competition.

During the past year, through the cooperation of Dr. M. A. McCall, Division of Cereal Crops and Diseases, U. S. Dept. of Agriculture and the *Northwestern Miller* of Minneapolis, the sum of $100 has been made available for the essay competition. It is hoped that it may be possible to conduct the essay contest within another year.

H. K. Wilson, *Chairman*
R. L. Cushing
G. H. Dungan
J. B. Peterson
M. B. Sturgis
J. W. Zahnley

MONOGRAPHS

THE committee has not made definite plans for monographs to be prepared during the war period. It is felt that after the war arrangements can be made for the preparation of some badly needed monographs. Among titles suggested for emphasis are the following:

The effects of climate and soil on crop plants
The use of lime on soils
Photoperiodism and crop adaptability
Phosphorus in soils: its chemistry and relation to plant growth
Temperature and the adaptation of plants
Clay minerals in soils
Physiological and ecological aspects of light in the growth, development and adaptation of plants
Tests for plant nutrients in soils
Foliar diagnosis for deficiencies of nutrients in soils
Sulphur and soil fertility
Soil moisture (how held, forces involved, and rate of movement)
Factors influencing permeability of soil and infiltration of water
Chemistry of soil organic matter

The committee believes that suitable arrangements may be made for publication by *Chronica Botanica*, or in some other suitable form. The principal problem is the one of encouraging the sustained interest of scientists qualified to prepare the types of monographs which the Society can sponsor. Suggestions for titles, and especially for authors, will be welcomed by the committee.

Charles E. Kellogg, *General Chairman*

For Crops:
H. H. Laude, *Chairman*
E. N. Furgus
S. C. Salmon

For Soils:
W. H. Pierre, *Chairman*
O. C. Magistad
R. M. Salter

VARIETAL STANDARDIZATION AND REGISTRATION

THE committee continued its work throughout the year, although the nine applications for varietal registration which it was hoped could be reported upon at this time have not yet completed circulation among the various members of the committee.

M. A. McCALL, *Chairman*

A. C. ARNY	E. A. HOLLOWELL
F. N. BRIGGS	R. E. KARPER
H. B. Brown	W. J. MORSE
J. A. CLARK	T. R. STANTON
L. F. GRABER	T. M. STEVENSON
H. K. HAYES	G. H. STRINGFIELD

NOMENCLATURE OF GENETIC FACTORS IN WHEAT

THE committee has only a progress report to present again this year. All the committee members have submitted detailed reports of the characters assigned to them and these are now being assembled. It is hoped to submit a final report by the next meeting of the Society.

It is recommended that the present committee be continued another year.

E. R. AUSEMUS, *Chairman*	J. P. HARRINGTON
F. N. BRIGGS	L. P. REITZ
W. W. WORZELLA	

CROP TERMINOLOGY

THE committee has had only a few words submitted to it in the past year. In view of the cancellation of the meetings for this year, the committee is submitting a report on these few additional words, and recommends that they be voted on by the Crops Section at its next meeting, along with the recommendations made in 1943.

Sweetclover or *sweet clover*

The compounding of this word follows the same rule as the word "canarygrass", concerning which recommendation was made last year. The compounding of names in "Standardized Plant Names" seems entirely arbitrary until the general rule is understood, when it becomes clear to one familiar with plant classification. Since it is not clear to others, it remains a serious question whether the system in its entirety will ever become standard in any real sense.

The editors of "Standardized Plant Names" have chosen one English name for each genus as the equivalent of the Latin genus name. "Clover", e.g., is the English equivalent of the Latin *Trifolium; Trifolium pratense* is red clover, *Trifolium repense* is white clover, and so on. But sweet clover does not belong to the genus *Trifolium;* in common usage "sweet clover" is the general, or generic, term for members of the genus *Melilotus*. In this, as in a multitude of similar situations, "Standardized Plant Names" suggests compounding the name, so that any English name ending in "clover" not compounded will definitely belong to the genus *Trifolium*, and any English name ending in "sweetclover" will belong to the genus *Melilotus*

The committee recommends that agronomists follow this system insofar as it is merely a printing convention; that is, when it means merely writing as one

word terms already actually in common use as two- or three-word names. It therefore recommends that agronomists use the form "sweetclover". Bluegrass (*Poa*), orchardgrass (*Dactylis*), and ryegrass (*Lolium*) are additional examples, out of many.

White clover, white Dutch clover, Dutch white clover

The seed trade, especially, refers to *Trifolium repens* as white Dutch clover, and many agronomists do likewise. There seems to be no reason for the agronomist to do this except when the seed actually comes from Holland and "Dutch" is being used as a source or strain, not a species, designation. The committee recommends the use of "white clover", omitting "Dutch", with the exception above; in that instance the term should be "Dutch white clover", not "white Dutch clover".

Ryegrasses

There are two species of ryegrass, *Lolium perenne*, known as perennial ryegrass or English ryegrass, and *L. italicum*, known as Italian ryegrass or annual ryegrass. On the Pacific coast a naturalized mechanical and perhaps genetic mixture of the two has been harvested for seed and sold as "domestic" or "common"[1] ryegrass.

"Standardized Plant Names" prefers "perennial ryegrass" and "Italian ryegrass", for *L. perenne* and *L. italicum*, respectively, and these terms have been in much more general use. "English" ryegrass is not called so in England or elsewhere in the British Empire. "Perennial" ryegrass is acceptable thruout the English-speaking world. Italian ryegrass is not an annual, so that term is misleading. The term "common" ryegrass is not too satisfactory, since it is to be hoped that these nondescript mixtures will soon cease to be "common", and be replaced by pure species and named varieties of them. However, some distinguishing term is needed, this term is in use, and no other term seems to the committee to be more satisfactory. The committee recommends the names "perennial ryegrass", "Italian ryegrass", "common ryegrass", as outlined above.

Naturalized, native, wild, natural, and similar expressions

There has developed a need for a term to be applied to strains of plants introduced from other countries which have become established in and more or less adapted to a given region by long-continued growth there. The need has come up particularly with regard to pasture plants, such as white clover, bluegrass, and bromegrass, but the use might be extended to other open-pollinated crops. The greatest confusion is in connection with white clover.

In this country "wild white clover" has become the trade mark of *English* wild white clover. Furthermore, the term "wild" is not properly used in this country because the plant is introduced. The same objection applies to "native". "Natural" has fewer connotations in connection with plant growth than "native", and is otherwise open to the same objections. "Naturalized" describes exactly what has taken place—it is the accurate word for the plants in question. Although the objection has been raised that it is too long, it does not seem that that will make any serious difficulty in this connection. If such material gets into commercial channels, it will doubtless be designated by the name of the state from which it comes, as has already occurred with "Louisiana white clover". The

[1]Schoth, H. A., and Hein, M. A. The ryegrasses. U.S.D.A. Leaflet, No. 196. 1940.

committee recommends the term "naturalized" white clover, bluegrass, and so on for other plants where the term is appropriate.

Mixtures

A criticism has been offered of the term "companion crops", proposed by the committee last year, that it does not distinguish between "nurse crops" and crop mixtures such as the universal clover-timothy mixture. The committee recommends that the term "mixture(s)" be used for crops which are grown and *harvested* together. The committee sees no objection to or confusion in the use of "companion crops" for all instances of crops growing together, but harvested separately, even though this use is somewhat wider than the old term "nurse crops".

C. J. WILLARD, *Chairman*
K. S. QUISENBERRY
C. P. WILSIE

RESOLUTIONS

THE committee most respectfully calls to the attention of all members of the American Society of Agronomy, the names of seven of our members who have been taken from us since our last report, as follows:

William Orr Whitcomb, Superintendent of the Montana Grain Inspection Laboratory, Bozeman, Mont., died June 11, 1944.

John Richard Fain, Professor Emeritus, University of Georgia College of Agriculture, Athens, Ga., died March 26, 1944.

Clyde Hadley Myers, Professor of Plant Breeding, Cornell University, Ithaca, N. Y., died August 5, 1944.

James Adrian Bizzell, Professor Emeritus of Soil Technology, Cornell University, Ithaca, N. Y., died November 1, 1944.

Harry Vaughn Harlan, in charge of barley investigation, U. S. Dept. of Agriculture, Sacaton, Ariz., died November 6, 1944.

Edward Franklin Gaines, Professor of Genetics in Agronomy, State College of Washington, Pullman, Wash., died August 17, 1944.

William Ap Catesby Jones, State Chemist of Virginia, Richmond, Va., died July 10, 1944.

Appended to this report are statements summarizing the life and professional work of these men and expressing the sincere sorrow and sense of loss on the part of the American Society of Agronomy. Our sympathy goes out to their respective families, the institutions which they served, and their former associates. Copies of these resolutions as published in the JOURNAL will be sent to the bereaved families.

IDE P. TROTTER, *Chairman*
B. B. BAYLES
R. W. CUMMINGS
R. I. THROCKMORTON
J. D. LUCKETT, *ex-officio*

WILLIAM ORR WHITCOMB

WILLIAM ORR WHITCOMB, Superintendent of the Montana Grain Inspection Laboratory and Professor of Agronomy in the Montana Agricultural Experiment Station, died at his home in Bozeman, Montana, June 11, 1944.

Mr. Whitcomb was born in Crary, North Dakota, November 25, 1884. He attended North Dakota State College, receiving his bachelor of science degree in 1909. He was granted the master of science degree from Cornell University in 1914 and spent one year at the University of Minnesota doing graduate work.

From 1909 to 1912 he was assistant in the Division of Dry Land Agriculture, U. S. Dept. of Agriculture. He came to Montana State College in 1913 as Assistant Professor of Agronomy and served in this capacity until 1919–20, when he was made Seed Market Specialist in the U. S. Dept. of Agriculture. Since 1920 he had served as Professor of Agronomy and Superintendent of the Montana Grain Inspection Laboratory.

Mr. Whitcomb devoted most of his time to the many problems encountered in a state seed laboratory where seed testing, protein testing, grain grading, and milling and baking studies are conducted. His main interest was in seed testing and milling and baking work. He has done much to help standardize methods of seed testing and particularly methods of evaluating hard seeds in leguminous seed crops. He also gave considerable time and effort to a study of the factors affecting the quality of wheat and flour for milling and baking purposes.

Professor Whitcomb was a tireless and efficient worker both in the field of his choice and the many organizations of which he was a member. He was the author of many experiment station bulletins and scientific papers on seed testing and related subjects. He was a member of the American Society of Agronomy, the Association of Official Seed Analysts of North America (President in 1935–36), the American Association of Cereal Chemists and its Northwest Section, and Phi Kappa Phi and Alpha Zeta honorary fraternities. He was an elder in the Presbyterian church and was clerk of its Session for many years. His sincerity of purpose and careful exactness made a lasting impression on those with whom he worked.—A. H. Post.

JOHN RICHARD FAIN

DOCTOR JOHN RICHARD FAIN, Professor Emeritus, University of Georgia College of Agriculture, passed away March 26, 1944, while attending Sunday School at his home in Jefferson City, Tennessee.

Upon being made Professor Emeritus on September 1, 1938, Doctor Fain retired to the place of his birth, Jefferson County, Tennessee, in which county he was born December 7, 1873, and continued to live at his farm until his death.

This eminent southern educator received his first college preparatory work at Carson-Newman College and was granted his bachelor of science degree from the University of Tennessee in 1900. The University of Georgia conferred on him the honorary degree of Doctor of Science in 1921.

While serving as superintendent of the farm of the Agricultural College of the University of Tennessee from 1898 to 1904, Doctor Fain was called as Assistant Professor of Agriculture at the Virginia Polytechnic Institute. He held this position for two years transferring in 1906 to the University of Georgia College of Agriculture to head the Department of Agronomy in the newly organized college. This position he held for 31 years.

Doctor Fain was a member of the American Society of Agronomy, the American Association for the Advancement of Science, the American Association of University Professors, the Farm Economics Association, the National Education Association, the Georgia Academy of Science and the Association of Southern Agricultural Workers.

The passing of Doctor Fain removes from southern agriculture one of those staunch patriots for all that is worthwhile in farm life and the many hundreds of students who passed under his guidance will long cherish his memory.—A. D. Stuart.

CLYDE HADLEY MYERS

DOCTOR CLYDE HADLEY MYERS, Professor of Plant Breeding and Plant Breeder in the Cornell Agricultural Experiment Station, died at Ithaca, New York, August 5, 1944. He is survived by his wife, Fleda Straight Myers, a son, Captain John S., of the U. S. Army, and a daughter, Marylee.

Doctor Myers was born February 6, 1883, at Randolph, Illinois. He obtained his Bachelor of Science degree from Illinois Wesleyan University in 1907. He served as Assistant in Plant Breeding at the University of Illinois from 1907 to 1910, at which time he received the Master of Science degree. He then entered the Graduate School of Cornell University, where he continued his studies in genetics and plant breeding. In 1912 the degree of Doctor of Philosophy was conferred upon him. In that year he was appointed Assistant Professor of Plant Breeding and in 1913 became Professor of Plant Breeding.

Doctor Myers' interests in research were largely concerned with bud-variation problems and the effects of environment on the hereditary characters of plants. He chose potatoes as one of the crops for experimentation and showed that hereditary changes in the plant and tuber characters were in certain cases due to alteration of the germ plasm. His experiments with potatoes had a definite practical bearing on methods used in bud-selection work. In his teaching he gave emphasis to these methods as a means of isolating superior germ plasm.

During these earlier years Doctor Myers also engaged in extensive experiments in corn improvement, applying the principal method then in use, the ear-to-row method. Certain experiments which had been begun by Doctor H. J. Webber, were carried further by Doctor Myers. He developed three varieties of corn, one of which, Cornell 11, is still the best open-pollinated variety for grain production now existent in New York State.

From 1912 to 1916, Doctor Myers gave much of his time to extension work, stressing particularly hill selection of potatoes and mass selection of corn. From 1916 he devoted most of his time to breeding timothy, alfalfa, and cabbage. He produced two very good varieties of timothy and several highly uniform strains of cabbage. A memoir prepared by Doctor Myers shortly before his death, dealing with methods for cabbage breeding, has now been published as Cornell Memoir 259.

Doctor Myers for a number of years conducted a course in plant breeding which was very popular, and in which he dealt fully with the known methods of plant improvement. His research work also attracted a number of graduate students, especially those interested in vegetable breeding and genetics.

Doctor Myers also helped organize the Crop-Improvement Program for China, which was a cooperative project between the University of Nanking, the former International Education Board, and Cornell University. In developing this program he spent the greater part of the years 1926 and 1931 in China, where he supervised a large program of plant breeding and conducted classes for training Chinese in the methods of plant breeding and genetics.

He was a member of numerous professional and honorary societies, among which were the American Association for the advancement of Science, American Genetic Society, American Society of Agronomy, Sigma Xi, and Gamma Alpha.

In 1939 Doctor Myers suffered a breakdown in health, a circumstance which eventually necessitated his retirement. To his colleagues, accustomed to the charm of his unique personality, and to his wide circle of friends and associates, this was a matter of much concern. Loyalty to his department and the things

for which it stands was one of his outstanding characteristics. Ever a hard worker, he was never too busy to assist student or colleague in meeting situations or aiding in the solution of problems. Sympathetic understanding characterized his professional and social contacts and to this was added a fine geniality and a keen but always kindly wit.

Among his coworkers in the Department of Plant Breeding, Doctor Myers' untimely disability was a matter of sincere regret. To them and to his other friends his sudden passing has brought a deep sense of loss.—H. H. LOVE.

JAMES ADRIAN BIZZELL

AFTER 43 years of association with Cornell University, James Adrian Bizzell, Professor of Soil Technology Emeritus, died November 1 at the age of 68 years. During this long period he served New York State and Cornell University faithfully and well. To his credit are many graduate students who are proud to have worked under his direction. Of even greater importance, perhaps, are his research publications on the chemistry of soils and crops, contributions that are recognized as authoritative and conclusive.

Born in 1876 on a farm near Fayetteville, North Carolina, James A. Bizzell received his early scientific training at the State Agricultural and Mechanical College of that state. There he was granted the degree of Bachelor of Science in 1895 and Master of Science in 1900. At the suggestion of Dr. W. A. Withers he then came to Cornell University, majoring in chemistry under the direction of Dr. G. C. Caldwell. In 1903 the degree of Doctor of Philosophy was conferred on him by this institution.

In 1907, Doctor Bizzell was appointed Assistant Professor of Soil Technology in the New York State College of Agriculture at Cornell University. In this position he was associated from the very first with the late Doctor T. Lyttleton Lyon, a Cornell graduate returning to the University as head of the newly created Department of Soil Investigations. The joint research of these two men during the succeeding 30 years was destined to make history in the field of soil science. Their names are irrevocably linked by the joint authorship of their publications. Advanced to a full professorship in 1912, Professor Bizzell continued active in his chosen research until July 1, 1944, when he retired as Emeritus Professor of Soil Technology.

The published research of James Adrian Bizzell in association with T. Lyttleton Lyon is well known to every soil scientist both at home and abroad. Written with scrupulous care, each publication, whether a memoir, bulletin, or journal article, attests the accuracy and completeness of the project and the soundness of the conclusions drawn. Of highest merit perhaps are the studies of the losses of plant nutrients in soil drainage as measured by lysimeters, the influence of plants on nitrate accumulation in soils and upon succeeding crops, the intricacies of nitrogen mobilization in soils, and the economic fertilization of crop rotations. Not one of these investigations has failed to throw valuable light on certain important theoretical and practical agronomic questions.

With the death of James Adrian Bizzell the associated accomplishments of Doctors Lyon and Bizzell come to a close, leaving the science and practice of agriculture immeasurably richer.—H. O. BUCKMAN.

HARRY VAUGHN HARLAN

DOCTOR HARRY VAUGHN HARLAN, 62, in charge of barley investigations in the Bureau of Plant Industry, Soils, and Agricultural Engineering, U. S. Dept. of Agriculture, died on November 6 at Phoenix, Arizona.

Doctor Harlan was born at London Mills, Ill., and was a graduate of Kansas State College in the class of 1904. He obtained his degree of Sc. D. from the University of Minnesota in 1914.

From 1905 to 1908 he was in charge of teaching and research at Iloilo and Bayambang in the Philippine Islands.

From 1910 until his death Doctor Harlan was in charge of barley investigations for the U. S. Dept. of Agriculture. In this position he made many contributions to the improvement of barley varieties, both in materials and in methods, and in methods of production. Much of the barley acreage in the United States is now planted to improved varieties resulting directly or indirectly from his work.

In 1913 and 1914 Doctor Harlan did agricultural reconnaissance in the highlands of Peru.

In 1919 the U. S. Grain Corporation and American Relief sent him to Central Europe and the Balkans to survey cereal production and available food supplies. In 1923 he did exploration work in barley areas of North Africa, Abyssinia, and India, and brought together one of the world's largest collections of barley varieties.

He was the author of many scientific papers and contributed articles on his travels to the *National Geographic* and other magazines. He was a fellow of the American Association for the Advancement of Science, a member of the American Society of Agronomy since 1917, the Washington Academy of Science, the American Genetic Association, and the Cosmos Club of Washington, D. C.

Doctor Harlan is survived by his wife, Augusta Griffing Harlan, and two sons, Wilbur Vaughn of the U. S. Army, and Jack Rodney of the Woodward Field Station, U. S. Dept. of Agriculture, Woodward, Oklahoma.—M. A. McCall.

EDWARD FRANKLIN GAINES

Edward Franklin Gaines, Cerealist of the Washington Agricultural Experiment Station and Professor of Genetics in Agronomy, State College of Washington, Pullman, Washington, died August 17, 1944, at the age of 58 years.

Doctor Gaines graduated from the State College of Washington in 1911 and received the M.S. degree from there in 1913. He received the degree of D.Sc. from Harvard University in 1921.

In 1913 he was made a full-time member of the Washington Agricultural Experiment Station Staff. Except for short periods of time used for study and travel, he spent practically his entire professional life at the Washington State College. Most of his time was given to research in genetics and to cereal crop improvement. However, a portion of his time was used for instruction, particularly for graduate students.

About the time Doctor Gaines started his work at the Experiment Station, one of its major activities was centered on the smut problem of wheat and methods of combating this disease. Smut not only reduced the yield and quality of wheat but caused serious losses from fires in threshing machines and in nearby fields. Agronomists, plant pathologists, and other scientists at the Experiment Station were asked to work on this problem.

Preliminary tests conducted in the cereal nursery in the years immediately following showed that different wheat varieties reacted differently to smut. Certain varieties, such as Hybrid 128 and others extensively grown at that time, were susceptible to this disease. Still others were found which did not have satisfactory field habits yet were highly resistant. Doctor Gaines was of the opinion that the resistance to this disease could be transmitted to hybrid offspring and

that a variety of wheat combining the good qualities of both parents and adapted to wheat-growing conditions of eastern Washington could be produced.

Working with other members of the Experiment Station staff and with the Division of Cereal Crops and Diseases of the U. S. Dept. of Agriculture, Doctor Gaines took a place of leadership in a wheat-improvement program centered at the Agricultural Experiment Station of the State College. The development of superior varieties of wheat that have been made available to farmers are practical contributions resulting from this wheat-improvement program. Their use reduced smut losses to a small percentage to what they previously had been and resulted in greater financial returns to wheat farmers and a better agriculture. The research conducted by Doctor Gaines resulted in the addition of new knowledge to the field of genetics and plant breeding.

Doctor Gaines spent a considerable portion of his time with graduate students who were assigned to problems in genetics. The problems usually dealt with the mode of inheritance of certain characters in hybrid offspring. Problems were selected so the efforts of individual students working with him resulted in new information and a substantial contribution in the field of genetics. The instruction and inspiration which his students received were important factors in developing their capabilities. The positions of responsibility that they occupy and their accomplishments attest the quality of instruction they received.

He was associated with various agricultural and professional organizations. He was a fellow and at one time Vice President of the American Society of Agronomy. He served on various committees of the Society and contributed technical papers to its JOURNAL. His many other scientific papers have been published in various scientific journals and as bulletins of the Washington Agricultural Experiment Station. He was a christian gentleman of varied interest and superior accomplishments.

Doctor Gaines was born at Avalon, Missouri, January 12, 1886, where he spent his early childhood. From there he moved with his parents and other members of his family to Stevens County, Washington. He acquired an education while working on the farm and in the woods and attending country schools and the State Normal at Cheney, Washington. With this background he entered the State College.

He is survived by his wife, Xerpha McCulloch, and their children, Edward, Mae (Mrs. Ramon L. Kent), John and Grant.—E. G. SCHAFER.

WILLIAM AP CATESBY JONES

MAJOR WILLIAM AP CATESBY JONES, State Chemist of Virginia, died on July 10, 1944, at the age of 63.

Major Jones, son of T. Catesby and Rosalie Fontaine Jones, was born June 9, 1881, at Lynchburg, Virginia, and was related through both parents to many families conspicuous in Virginia history. His grandfather was president of the Virginia Central Railroad, now the Chesapeake and Ohio.

Major Jones graduated at Virginia Polytechnic Institute in 1900 and spent the following 12 years as a chemist with iron and steel laboratories in Virginia, Alabama, and Pennsylvania. In 1913, he joined the scientific staff of the Virginia Department of Agriculture, and in 1930 became State Chemist, which position he held at the time of his death.

He was a charter member of the Virginia Section of the American Chemical Society and served as chairman and counselor. He helped organize the Virginia Academy of Science and served ably in the office of president. In 1934 in recogniza-

tion of his contributions to science, he was elected a Fellow in the American Institute of Chemists. He was a charter member of the Southern Association of Science and Industry, serving as a member of its executive committee at the time of his death.

He was an active member in the Alumni Association of his Alma Mater, many committees authorized for scientific study by the General Assembly of Virginia, and was past master in Virginia of the National Grange.

He was a past president of the Central Atlantic States Dairy, Food, and Drug Officials and at the time of his death was president of the Association of American Feed Control Officials and a member of the executive committee of the Association of Official Agricultural Chemists.

Major Jones was an active member of the 40 and 8 Society and the American Legion in which he had served in many positions of responsibility. At the time of his death, he was National Committeeman from Virginia.

He was a member of historical St. Paul's Episcopal Church where for many years he served as vestryman.

Though he was quiet and unassuming, he was energetic and possessed all of the characteristics necessary to make a good leader of men. He was loyal, genial, and devoted to all that was best in science, social and civic life. He lived a full life as head of a devoted family and as a public servant. His patriotism made him not only a good soldier but an exemplary private citizen. He was truly a friend of man.—RODNEY C. BERRY.

OFFICERS OF THE AMERICAN SOCIETY OF AGRONOMY FOR 1945

President, F. W. PARKER, U. S. Dept .of Agriculture, Research Center, Beltsville, Md.

Vice President, H. D. HUGHES, Iowa State College, Ames, Iowa.

Chairman of Crops Section, I. J. JOHNSON, Iowa State College, Ames, Iowa.

Chairman of Soils Section, L. D. BAVER, North Carolina State College, Raleigh, N. C.

Secretary-Treasurer, G. G. POHLMAN, University of West Virginia, Morgantown, W. Va.

Editor, J. D. LUCKETT, New York State Experiment Station, Geneva, N. Y.

Members of the Executive Committee, F. D. KEIM, University of Nebraska, Lincoln, Nebr.; and RICHARD BRADFIELD, Cornell University, Ithaca, N. Y.

OFFICERS OF THE SOIL SCIENCE SOCIETY OF AMERICA FOR 1945

President, L. D. BAVER, North Carolina State College, Raleigh, N. C.

Vice President, C. E. MARSHALL, University of Missouri, Columbia, Mo.

Past President, FIRMAN E. BEAR, Rutgers University, New Brunswick, N. J.,

Secretary-Treasurer, G. G. POHLMAN, University of West Virginia, Morgantown, W. Va.

Editor, J. D. LUCKETT, New York State Experiment Station, Geneva, N. Y.

SECTION I—SOIL PHYSICS

Chairman, G. M. BROWNING, Iowa State College, Ames, Iowa.
Vice Chairman, BYRON T. SHAW, Research Center, Beltsville, Md.
Past Chairman, G. W. CONREY, Ohio State University, Columbus, Ohio.

SECTION II—SOIL CHEMISTRY

Chairman, C. O. ROST, University of Minnesota, St. Paul, Minn.
Vice Chairman, GARTH W. VOLK, Alabama Polytechnic Institute, Auburn, Ala.
Past Chairman, HANS JENNY, University of California, Berkeley, Calif.

SECTION III—SOIL MICROBIOLOGY

Chairman, S. C. VANDECAVEYE, Washington State College, Pullman, Wash.
Vice Chairman, T. M. MCCALLA, Soil Conservation Service, Lincoln, Nebr.
Past Chairman, HERBERT W. REUSZER, Alabama Polytechnic Institute, Auburn, Ala.

SECTION IV—SOIL FERTILITY

Chairman, R. E. YODER, Ohio Agricultural Experiment Station, Wooster, Ohio.
Vice Chairman, W. R. PADEN, Clemson Agricultural College, Clemson, S. C.
Past Chairman, B. A. BROWN, University of Connecticut, Storrs, Conn.

SECTION V—SOIL GENESIS, MORPHOLOGY, AND CARTOGRAPHY

Chairman, JAMES THORPE, University of Nebraska, Lincoln, Nebr.
Vice Chairman, R. J. MUCKENHIRN, University of Wisconsin, Madison, Wis.
Past Chairman, R. E. STORIE, University of California, Berkeley, Calif.

SECTION VI—SOIL TECHNOLOGY

Chairman, HANS F. WINTERKORN, Princeton University, Princeton, N. J.
Vice Chairman, F. L. DULEY, University of Nebraska, Lincoln, Nebr.
Past Chairman, J. S. OWEN, University of Connecticut, Storrs, Conn.

INDEX